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Abstract

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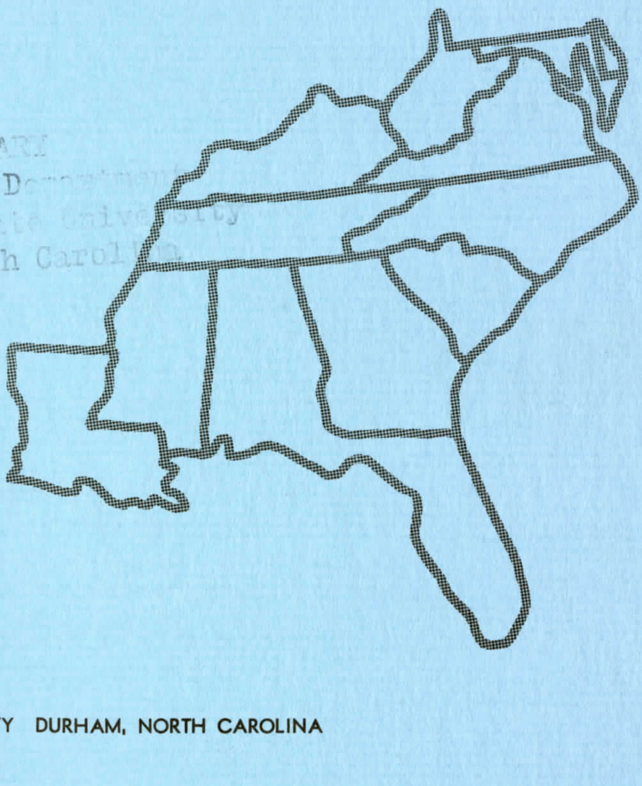

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SOUTHEASTERN GEOLOGY

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LITTLE WAR GAP AT CLINCH MOUNTAIN PROVIDES STANDARD REFERENCE SECTION FOR SILURIAN CLINCH SANDSTONE AND MOST NEARLY COMPLETE DEVONIAN SECTION IN EASTERN TENNESSEE

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ABSTRACT

New cuts along Tennessee Route 70 at Little War Gap through the crest of Clinch Mountain in Hawkins County display excellent Silurian and Devonian exposures. White to yellowish gray quartz arenite on Clinch Mountain forms the type locality of Silurian (Llandovery) Clinch Sandstone, which overlies the grayish red strata of the Juniata Formation (called Sequatchie Formation by some geologists) with apparent conformity. In the Clinch Sandstone, a basal 269 feet of massive, silica-cemented quartz arenite is overlain by about 42 feet of silica-cemented quartz arenite and siltstone of Rockwood facies. A topmost 17 feet of sandstone, more friable and marine fossiliferous, has an unconformity at its base and is not included in the Clinch Sandstone, but instead is assigned to the Devonian Wildcat Valley Formation of Miller, Harris, and Roen (1964). The lower nine feet of Wildcat Valley is friable quartz-arenite with a basal conglomerate; this portion contains Devonian Oriskany-age fauna with large <u>Dalejina musculosa</u>, <u>Rensselaeria</u>, <u>Costispirifer</u>, and <u>Edriocrinus sacculus</u>. An overlying eight feet of glauconitic sandstone contains Schoharia-age fauna with <u>Pentamerella</u>, <u>Plicanoplia</u>, <u>Fimbrispirifer</u>, <u>Pentagonia</u>, and <u>Leptocoelia flabellites</u>. An additional foot of dark gray silty shale contains <u>Plicoplasia</u>, <u>Eodevonaria</u>, and <u>Leptocoelia flabellites</u> and is of early Onesquethaw-age; on lithologic basis it is assigned to basal Chattanooga Shale.

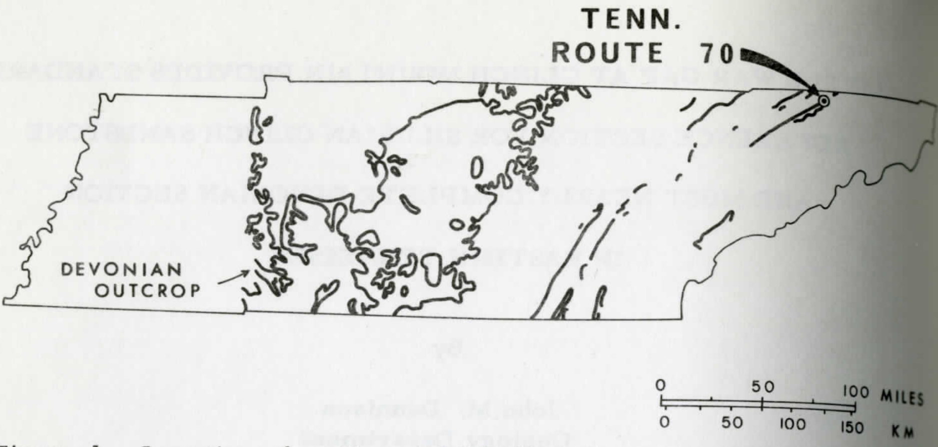

Figure 1. Location of section at Little War Gap where Tennessee Route 70 crosses Clinch Mountain.

The Chattanooga Shale is about 2,140 feet thick. Four Tioga Bentonite tuff layers occur in the basal 27 feet of Chattanooga. Black shales in the lower Chattanooga span Cazenovia to probable Cassadaga Stages. The highest Styliolina occurs 105 feet above the Chattanooga base. Siltstones 1,305 to 1,556 feet above the Chattanooga base are intertongues from the northeast of Brallier lithology of Cassadaga Stage and younger. An upper Chattanooga interval lacks siltstone and probably represents the Big Stone Gap Shale Member (latest Devonian and possibly some early Mississippian).

INTRODUCTION

The extensive cuts along Tennessee Route 70 at the southeast slope of Clinch Mountain (Figure 1) display excellent exposures of the stratigraphic interval from the Juniata Formation (Upper Ordovician) through the Grainger Formation (Lower Mississippian). This outcrop is here designated the type exposure of the Clinch Sandstone. The relations of the Clinch with the overlying Chattanooga Shale are better exposed along Route 70 than elsewhere in Tennessee. The Devonian System is thicker and more completely represented there than in any other single section known in eastern Tennessee, and it may even exceed all localities on the west side of the Nashville Dome for completeness of Devonian stratigraphic record.

This paper began with work initiated by Dennison in 1966. After the profuse Lower Devonian faunas were discovered in new highway cuts, Boucot visited the site in 1967 and began a detailed study of about a hundred pounds of selected material from the Lower Devonian strata. Weathering is rapid in these critical outcrops, so already additional collecting is difficult from certain beds. It is important, therefore, to record in as much detail as possible a description of the rocks and fauna during the time of best exposure.

Previous Work

The earliest significant work in the region was Stafford's (1869) volume on the Geology of Tennessee. The Clinch Mountain area was mapped at a scale of 1:125,000 in the Morristown folio (Keith, 1896), and by Rodgers (1953). The Pressmens Home area near Little War Gap was also mapped in an unpublished dissertation at Yale by John E. Sanders (1952).

Swartz (1929, p. 442-444) described measured sections of the Chattanooga Shale about eight miles southwest of Little War Gap at Stone Mountain and at Klondyke. Harris and Miller (1958) noted in the text accompanying their geologic map of the Duffield Quadrangle, Virginia, the presence of Lower Devonian fauna (identified by Boucot) in sandstone at the southeast base of Clinch Mountain at Little War Gap.

An abstract of this paper and preliminary oral report were presented at the Columbia, South Carolina, meeting of Southeastern Section of the Geological Society of America on April 11, 1969 (Dennison and Boucot, 1969).

Acknowledgments

Field discussion with Leonard D. Harris, who has mapped extensively in eastern Tennessee and nearby Virginia for the U. S. Geological Survey, was most helpful in relating our observations to previous work and clarifying relations of the Tioga Bentonite. Kenneth O. Hasson helped with a critical review of the manuscript and the field relations. Sondra W. Dennison drafted the illustrations.

This study was partially supported by a grant from the University of North Carolina Research Council and by National Science Foundation Contract No. GA17455.

ORDOVICIAN SYSTEM

The only Ordovician strata considered in the present study are the redbed sequence at the summit of Clinch Mountain at Little War Gap (units 1-7 in measured section in Appendix of this paper). These strata are chiefly grayish red with some light olive gray mudstone, with some fine sandstone and shale, and the authors prefer to designate them as the Juniata Formation. The Clinch Mountain outcrop belt is mapped as Juniata Formation on the new geologic map of Tennessee (Hardemann and others, 1966). There is a developing tendency to standardize the nomenclature applied throughout Tennessee and southwest Virginia to apply the name Sequatchie Formation to the reddish strata just beneath the Clinch Sandstone, even in the Clinch Mountain outcrop belt (Harris and Miller, 1958; Mixon and Harris, 1971) where the strata are conspicuously redder and contain less carbonate than outcrops to the northwest.

The Juniata and Sequatchie Formations are respectively the less and more calcareous portions of the same sedimentary sheet; they intergrade laterally and the boundary between them is essentially an arbitrary one (Rodgers, 1953, p. 97). The only published regional study of the stratigraphic and sedimentologic relationships of the Juniata and Sequatchie Formation is by Thompson (1970). He considers the Juniata facies to be red, unfossiliferous and relatively argillaceous; the Sequatchie facies is gray, fossiliferous and relatively limy. The Juniata is supratidal to fluvial in origin, and the Sequatchie facies is shallow subtidal. An intermediate facies is mottled to interlayered red and gray and is intertidal in origin. Dolomitic beds in the Juniata Formation are interpreted to originate on supratidal flats by early diagenetic replacement of calcite under desiccating conditions. By this standard, the name Juniata Formation seems most appropriate designation for the Route 70 exposures at Clinch Mountain. In Sequatchie Valley both reddish and gray beds occur in the limestones, shales and sandstones of the Sequatchie Formation type region. Fifteen miles to the southwest of Little War Gap, Mixon and Harris (1971) used the name Sequatchie Formation in the Clinch Mountain outcrop belt, but they applied it to strata consisting largely of grayish-red siltstone and shale. We think that nomenclature should be consistent with stratigraphic character and should be applied with criteria independent of political boundaries, even at the expense of necessitating more than one name for chronostratigraphic equivalents within a state. It is noteworthy that Chowns (1972, p. 5) applied the name "Juniata" facies in northwest Georgia to dark red unfossiliferous siltstones and sandstones which he considered alluvial sediments equivalent to the Sequatchie Formation.

The Juniata Formation seems to be definitely of Ordovician Richmond Age, based on regional intertonguing with marine fossiliferous beds of the Sequatchie Formation (Rodgers, 1953, p. 98). The lower beds may be slightly older Maysville age, based on evidence in southwestern Virginia (Miller and Fuller, 1954, p. 138; Miller and Brosgé, 1954, p. 75).

No evidence has been reported along Clinch Mountain to indicate an unconformity between the Juniata and Clinch Formations, so there apparently was continuous sedimentation across the Ordovician-Silurian boundary.

SILURIAN SYSTEM

The summit of Clinch Mountain (Figure 2) is formed by the resistant Clinch Sandstone, which is the sole representative of the Silurian

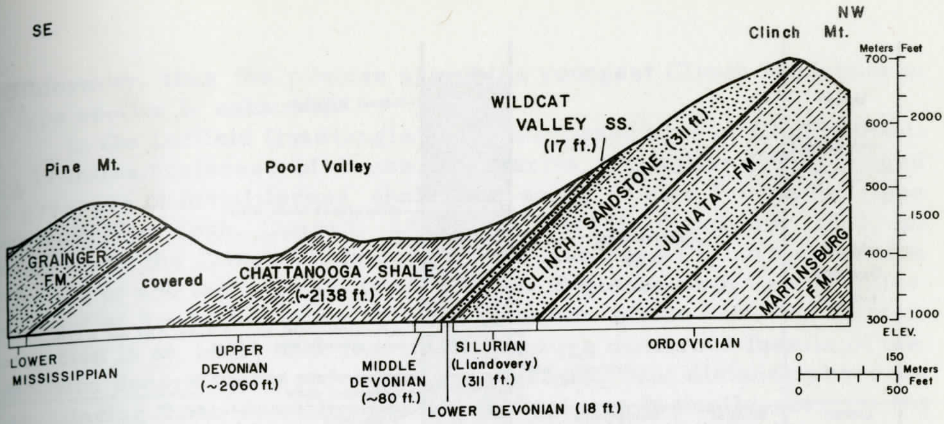

Figure 2. Cross section along Tennessee Route 70, between Pine Mountain and Little War Gap at crest of Clinch Mountain.

System in the strike belt. No specific type section outcrop has ever been designated for the Clinch Sandstone. Safford (1856, p. 157; 1869, p. 292-299) named it for Clinch Mountain, where this sandstone forms the greatest mountain in the Valley of East Tennessee. Rodgers (1953, p. 101) described the Clinch in its type region as thick-bedded massive white to lightly iron-stained nearly pure quartz sandstone commonly with a silica cement. The Clinch Sandstone was also described and mapped along Clinch Mountain by Sanders (1952). It is here proposed that the excellent exposures along Tennessee Route 70 serve as a type section for the Clinch Sandstone (see Appendix).

Safford's original definition of the Clinch Mountain Group included all those sandstones from the base of the reddish strata of the upper Ordovician (Clinch reddish shale of Safford, 1869, p. 293 ff.; now called Juniata Formation) to the base of the black Chattanooga Shale. The Clinch Sandstone of Safford (1869, p. 293) is the whitish sandstone overlying his Clinch Shale. Following Safford's original definition, the Clinch Sandstone at Tennessee Route 70 would be 328 feet thick in our plane-tabled section in the Appendix, but we restrict the Clinch definition in such a way that the Clinch Sandstone is 311 feet thick by our usage. Four stratigraphic divisions (Figure 3) can be recognized between the topmost Juniata redbeds and the basal shale of the Chattanooga: 1) resistant massive, whitish to yellowish gray sandstone with some quartz conglomeratic beds (269 feet) overlain by 2) resistant, whitish to yellowish gray sandstone with some silty interbeds (42 feet thick, representing the upper member of the Clinch Sandstone), in turn overlain by the Wildcat Valley Sandstone Formation consisting of 3) friable, coarse sandstone (9.4 feet) which weathers yellowish brown to dark yellowish orange at the bottom and 4) glauconitic, phosphatic sandstone (7.9 feet) at the top. The basal two units contain distinctive whitish quartz arenites or orthoquartzites and comprise the Clinch Sandstone

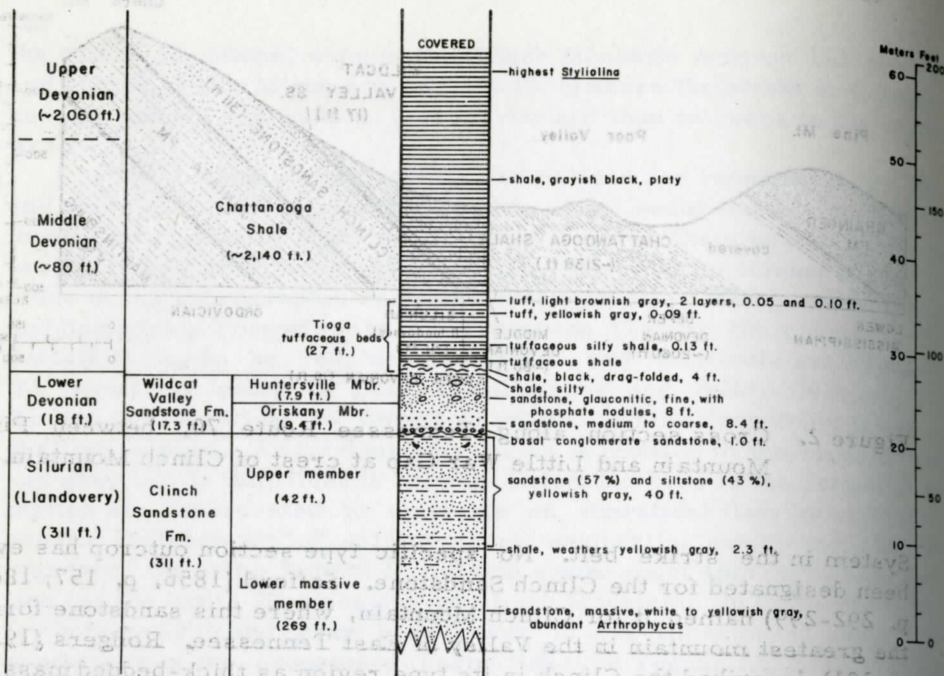

Figure 3. Details of upper Clinch Sandstone through lower Chattanooga Shale stratigraphic interval where Tennessee Route 70 crosses Clinch Mountain.

Formation at its here-designated type section, including a somewhat silty member at the top. Neither division of the Clinch has yielded megafossils except Skolithos and Arthrophycus, but regional stratigraphic relations indicate a lower Silurian (Llandovery) age. The upper two divisions of the original Clinch Sandstone total 17 feet in thickness; these calcitic and glauconitic sandstones are much less resistant than the orthoquartzites of the lower two units and are assigned to the Devonian Wildcat Valley Sandstone of Miller, Harris, and Roen (1964). At Route 70 both members of the Wildcat Valley contain abundant Early Devonian fossils.

The Silurian System at Route 70 is therefore 311 feet thick and is totally composed of the Clinch Sandstone Formation in its restricted sense with the Juniata Formation redbeds removed from the base and the Wildcat Valley Sandstone removed from the top. The basal contact of the Clinch Sandstone is placed at the top of a shale unit 3 feet thick, which contains the highest redbeds in its lower portion. There is no regional evidence along Clinch Mountain of an unconformity between the Clinch and older strata, so the basal Clinch is considered lowest Silurian. The Clinch is unfossiliferous at Route 70, except for Arthrophycus, Skolithos, and trails and burrows, and its top surface is an unconformity, thus the precise age of the youngest Clinch Sandstone in its type section is unknown.

In the Duffield Quadrangle at the southeast base of Clinch Mountain 17 miles northeast of Route 70, Harris and Miller (1958) record the presence of fossiliferous shaly and sandy Clinton Formation (type section in New York, Conrad, 1842, p. 229-231; Vanuxem, 1842, p. 79-90) above the Clinch Sandstone, with a combined Clinch and Clinton thickness of 450 feet. Near Gate City at Big Moccasin Gap 27 miles northeast of Route 70 along Clinch Mountain strike belt, the Clinton Formation is at least 200 feet thick, because numerous fossils of the Zygobolba decora ostracod zone are recorded that distance above its base, placing those fossiliferous strata paleontologically near the top of the Lower Clinton (Ulrich and Bassler, 1923, p. 538-539).

About 40 miles northwest of Little War Gap, in the Cumberland Gap region, which is separated from Clinch Mountain by several thrust faults, the Clinch Sandstone along the Cumberland Escarpment changes facies southwestward from massive Clinch Sandstone into more shaly Rockwood Formation. In Lee County, Miller and Fuller (1954, p. 140-149) divide the 257 feet of Clinch Formation into a lower Hagan Member (70-77 feet of shale with limestone) and an upper Poor Valley Ridge Member 183 feet of sandstone and shale). At Cumberland Gap Butts (1940, p. 232) recorded intertongues of limestone with a Brassfield (Alexandrian) marine fauna, confirming a lowest Silurian age for the Clinch. The Rockwood Formation was named by Hayes (1891) for outcrops along the Cumberland Escarpment near Rockwood, Roane County, Tennessee. Rodgers (1953, p. 100-101) considers the Rockwood a facies of the Clinch. The name Rockwood is widely used in eastern Tennessee from Cumberland Gap to Chattanooga for shaly, silty, and sandy strata which contain limestone intertongues and scattered hematite layers of former commercial value.

The upper 42 feet of silty beds in sandstone of the Clinch Formation at Route 70 is interpreted as intertonguing of the Rockwood lithology with the more massive Clinch. An alternative interpretation is to consider these 42 feet of silty beds at Route 70 as Clinton Formation, that extends southwestward from Big Moccasin Gap and the Duffield Quadrangle. No fossils have been found in these critical silty beds at Route 70, but the 42 feet of silty strata are considered Rockwood rather than Clinton by the following logic. It is thought that pre-Devonian erosion cut progressively deeper toward the west and beveled off the Clinton Formation somewhere near the Tennessee-Virginia boundary in the Clinch Mountain strike belt. The silty beds in the upper Clinch at Route 70 can be traced along strike to the southwest, and the entire Clinch along Clinch Mountain can be observed to become more silty southwestward, a relationship which is interpreted as intertonguing of classical Clinch and Rockwood lithologies. A comparable facies change was previously noted along the Cumberland Escarpment exposures.

The lithologic similarity of the Clinton and Rockwood formations has long caused nomenclature confusion. At Big Moccasin Gap in the Estillville Folio, Campbell (1894) applied the name Rockwood to strata that are in fact the southwestern extension of the main mass of Clinton Formation from farther northeast in Virginia.

DEVONIAN SYSTEM

The Devonian strata at Route 70 total approximately 2,155 feet in thickness; Wildcat Valley Sandstone (17 feet) is overlain by Chattanooga Shale (about 2,138 feet). The upper part of the Lower Devonian rests unconformably on the Silurian, but the Devonian section seems to contain no large stratigraphic gaps up through the basal Mississippian Grainger Formation. No fauna uniquely diagnostic of Esopus-age and Onondaga-age strata have been identified, but regional lithologic patterns suggest a likelihood of nearly continuous deposition through this time interval. The top of the Devonian is near the top of the Chattanooga Shale, but part of the uppermost 100 feet of the Chattanooga may be Mississippian in age.

Wildcat Valley Sandstone

The Wildcat Valley Sandstone was named by Miller, Harris, and Roen (1964) for sandstones and sandy to cherty limestones near Big Stone Gap, Virginia, which lie stratigraphically between the Late Silurian Hancock Limestone and the Black Devonian Chattanooga Shale. The Wildcat Valley Sandstone is 41 feet thick in its type section. Harris and Miller (1958) recognized this sandstone along Clinch Mountain in the Duffield Quadrangle, some 17 miles northeast of Route 70. In the same quadrangle report they record the sandstone at Little War Gap (Tennessee Route 70). Wildcat Valley Sandstone is present along the southeast base of Powell Mountain in the Stickleyville Quadrangle (Harris and Miller, 1963), 14 miles northeast of the Route 70 section at Clinch Mountain. The name Wildcat Valley Sandstone first appeared on a geologic map in the Big Stone Gap Quadrangle (Miller, 1965). Dennison has identified Wildcat Valley Sandstone in outcrop at the peridotite plug at Norris Lake; apparently the Helderberg fossils collected from limestone xenoliths in the peridotite (Hall and Amick, 1944) are Wildcat Valley strata which leach upon weathering to form friable sandstone. In different parts of eastern Tennessee, the Wildcat Valley Sandstone contains beds of late Helderberg, Oriskany, and early Onesquethaw (Schoharie) age. Locally in eastern Tennessee and southwestern Virginia, the entire Wildcat Valley is cut out by the pre-Chattanooga unconformity. At no place in eastern Tennessee are Helderberg-age strata known to occur in the same stratigraphic section with Oriskany-age or Schoharie-age beds.

The Wildcat Valley Sandstone on the dip slope at Route 70 is barely thick enough to map at 1:24,000 scale; it is divided into a lower Oriskany Sandstone Member (9.4 feet) and an upper Huntersville Member (7.9 feet) composed of glauconitic sandstone.

Oriskany Member. --The Oriskany Sandstone was named in New York by Vanuxem (1842, p. 123-127). The Oriskany Member at Route 70 consists of friable, coarse, quartz sandstone with abundant large brachiopods and a distinctive yellowish orange to yellowish brown weathering color. Lithologically, it resembles the Oriskany Sandstone in Virginia (Butts, 1940, p. 292-294). The fauna listed in the measured section clearly belongs to the Deerpark Stage and matches the well-known Oriskany fauna of New York. Unfortunately, the Route 70 section is weathering so fast that fossiliferous slabs of the friable Oriskany can no longer be collected.

The Oriskany was first reported along Clinch Mountain by Prouty (1935, p. 219) who noted 12 feet of Oriskany at Clinch Mountain two miles west of Stone Mountain. Prouty reports the Oriskany absent on Stone Mountain, and we agree. The Oriskany lithology was recognized at Bean Gap by Prouty (1935, p. 219), but noted as unfossiliferous. Dennison considers the sandstone at Bean Gap to be Oriskany rather than Helderberg lithology and noted one poorly preserved Platyceras near Route 25-E along the old road (former Route 25-E) leading up Clinch Mountain at Bean Gap. Fossiliferous Oriskany is exposed along present Route 25-E about a mile to the northeast. The Oriskany Member persists southwest as far as Route 25-E, but probably not much farther; to the northeast, the Oriskany is unknown on Clinch Mountain between Route 70 and Walker Gap in Bland County, Virginia (Dennison, 1961, Plate 3, Section V56). The Clinch Mountain belt is the only Oriskany known in eastern Tennessee.

Figure 4 shows the distribution and thickness of known Oriskany Sandstone in part of Tennessee, Virginia, West Virginia, Kentucky, and Ohio. The main Oriskany occurrence in the Appalachian Basin is overlain, conformably in most places, by Huntersville Chert or Needmore Shale. The three Oriskany patches shown beyond the margins of the Appalachian Basin are erosional remnants of a formerly larger Oriskany deposit, now isolated as a result of erosion beneath the Onesquethaw Stage along the southern margin of the Appalachian basin. The northeasternmost of these Oriskany patches was only recently identified (Eubank, 1967, 1968). The middle one (Dennison, 1961) occurs in parts of both the Clinch and Walker Mountain strike belts, where the Oriskany rests unconformably on Rocky Gap, Clinton, Tuscarora, and Juniata strata. The Tennessee patch is the most southwestern Oriskany Sandstone identified in the Appalachian region.

On the north edge of the Appalachian Basin, comparable erosional remnants of formerly continuous Oriskany Sandstone are preserved in Pennsylvania (Lytle and others, 1961) and New York (Kreidler, 1963).

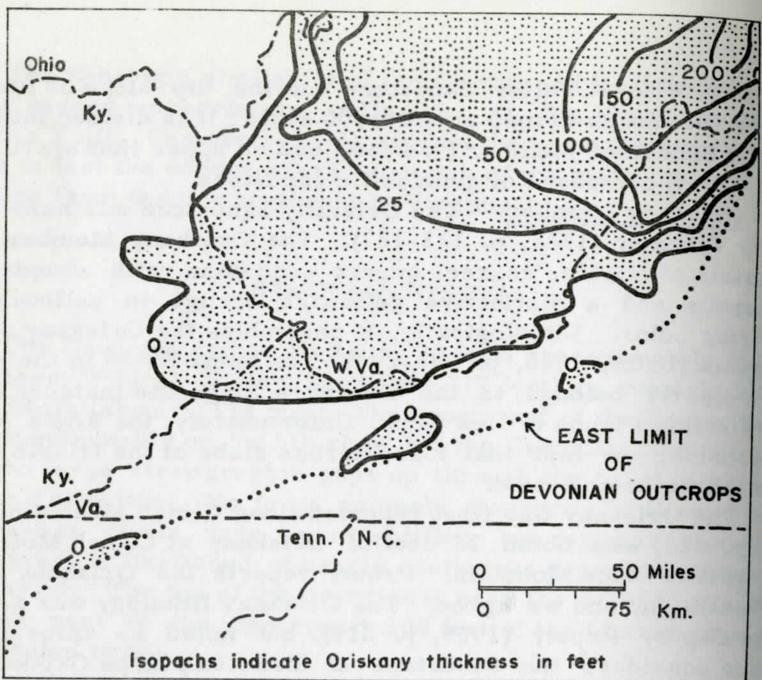

Figure 4. Dotted patterns show erosional remnant patches of Oriskany Sandstone near south edge of continuous Oriskany sand body in central portion of Appalachian basin.

The Oriskany at Clinch Mountain contains a basal foot of conglomeratic sandstone with Costispirifer. This conglomerate represents the marine transgression of the basal beds of the Piankasha Sequence after the Wallbridge discontinuity (Wheeler, 1963, p. 1511-1517; Dennison, 1970, p. 17-18). On the east edge of the craton and along the east margin of the Appalachian Basin, partial withdrawal of the sea resulted in a minor unconformity which locally removed the formerly continuous deposit of Oriskany Sandstone (Dennison, 1961, p. 12). The post-Oriskany unconformity is probably of less regional significance than the pre-Oriskany erosional vacuity. The post-Oriskany unconformity represents a minor oscillation of the sea as the cration was inundated after the Wallbridge discontinuity (Dennison, 1970, p. 18).

Huntersville Member. --The Huntersville Chert Formation was named by Price (1929, p. 236-237) for cherty strata with some sandstone and shale above the Oriskany Sandstone and below the Marcellus Shale. Dennison (1961) described the Huntersville Chert in the southern part of the Appalachian Basin. The Huntersville of southwest Virginia is principally a bedded chert with some sandstone interbeds. In Washington, Scott, and Wise Counties, Virginia, Huntersville Chert changes facies northwestward into Onondaga Limestone which has been traced northward into the subsurface across eastern Ohio into the Onondaga Limestone of New York. The Huntersville and Onondaga are assigned to the Onesquethaw Stage (Dennison, 1961; Oliver and others, 1967). Strata which Dennison (1960, p. 221-224; 1961) assigned to the Onesquethaw Stage near Big Stone Gap are included in the type section of the Wildcat Valley Sandstone of Miller, Harris, and Roen (1964). Dennison believes that the type section of Wildcat Valley Sandstone contains late Helderberg and Onesquethaw Stage strata, but that Deerpark Stage strata are not present in the Wildcat Valley type section.

At Route 70 on Clinch Mountain, the Huntersville Member of the Wildcat Valley Sandstone is represented by 7.9 feet of fine-grained, glauconitic sandstone with phosphatic nodules in the upper part. This is identical in lithology with the Bobs Ridge Member (Dennison, 1961, p. 33-35) of the Huntersville Formation. The glauconitic sandstone of the Bobs Ridge Member in Virginia and West Virginia occurs at the top of the Huntersville immediately below the Tioga Bentonite, just as the glauconitic sandstone at Clinch Mountain is immediately beneath the Tioga. There are other glauconitic sandstones lower in the Huntersville Chert of southwest Virginia in the Clinch Mountain outcrop belt, notably along Tumbling Run 4 miles southwest of Saltville, Washington County (Dennison, 1960, p. 209), along another Tumbling Run at Tannersville, Tazewell County (Dennison, 1960, p. 194); and at Virginia Route 16 (Dennison, 1960, p. 192). The Bobs Ridge Members which so strikingly resembles the sandstone at Route 70, occurs closest in the Clinch Mountain outcrop belt at Suiter, Bland County, Virginia (Dennison, 1960, p. 184; 1961, Plate 3). In the Virginia portion of the Clinch Mountain strike belt, the Huntersville Formation is missing by unconformity southwest of Washington County. In the Walker Mountain outcrop belt, the closest Bobs Ridge Sandstone to Tennessee Route 70 is at Route 16 in Smyth County, Virginia (Dennison, 1960, p. 199; 1961, Plate 3).

The fauna in the Huntersville Member at Route 70 is definitely of Onesquethaw age. Boucot interprets the Huntersville to be exclusively Schoharie age (lower Onesquethaw), and he considers that an unconformity may be present beneath it, accounting for the absence at Route 70 of Esopus-age fossils between the Oriskany and Huntersville fossiliferous strata shown in Figure 3. Boucot favors Schoharie deposition at Route 70 between the Huntersville Member and the overlying basal foot of Marcellus Shale, with a possible slight cessation of sedimentation or minor intra-Schoharie erosion at the base of unit 51. Dennison prefers to interpret the "Schoharie" fauna as a clastic facies fauna within the Onesquethaw Stage, and feels confident that all beds above the base of unit 53 in the measured section are post-Onesquethaw in age. Boucot has examined Dennison's brachiopod collections from Maryland, West Virginia, and Virginia, and see no definite faunal evidence of any strata younger than Schoharie-age in the Onesquethaw strata south of Pennsylvania. Dennison has traced the Tioga Bentonite in outcrops and in the subsurface with control spacing of no more than 20 miles from Route 70 to the type locality of the Onondaga Limestone in New York, where the Tioga occurs near the top of the Onondaga, and sees no physical stratigraphic evidence for an erosional break beneath or above the Tioga throughout that extent; thus he favors the presence of Onondaga-age beds at Clinch Mountain in spite of no specific fossil evidence supporting such an interpretation.

No chert was observed in the Huntersville Member at Route 70, although Sanders (1952) noted chert float at unspecified localities along the southeast base of Clinch Mountain in the Pressmen's Home mapped area and inferred that the chert never exceeded a foot in thickness. Regional patterns suggest that the chert should occur between the Oriskany Sandstone and the overlying glauconitic sandstone.

Chattanooga Shale

The major thickness of the Devonian at Route 70 is assigned to the Chattanooga Shale (2, 138 feet), named by Hayes (1891, p. 142-143) for exposures near Chattanooga, Tennessee. The section at Sligo bridge over Center Hill Reservoir seven miles east of Smithville, Dekalb County, Tennessee, has more recently been designated the standard reference section for the Chattanooga Shale (Conant and Swanson, 1961, p. 23-24). The basal contact at Route 70 is an abrupt change from friable, grayish orange-weathering sandstone upward to grayish black shale. The top contact of the Chattanooga is gradational, but the base of the Grainger Formation is located at the upward change to dominately siltstone. At the base of the Chattanooga Shale streaks of Tioga Bentonite (named in the subsurface of Tioga County, Pennsylvania, by Fettke in Ebright, Fettke, and Ingham, 1949, p. 10) can be recognized. In the upper third of the Chattanooga at Route 70 siltstone beds occur, representing tongues of the Brallier Formation (Butts, 1918), which is a siltstone and shale unit widely mapped in Virginia and northward into Pennsylvania. A thin interval of black shale intervenes between the top of these Brallier siltstones and the siltstones at the base of the Grainger Formation.

The basal 27 feet of Chattanooga Shale contains at least four feldspathic, micaceous siltstone streaks of Tioga Bentonite, plus numerous other very dark gray shale layers which weather into thin sheets with a slight brownish cast resulting from tuffaceous admixture. Over 120 Tioga outcrops have been identified between Pennsylvania and Tennessee (Dennison, 1960, 1961; Dennison and Textoris, 1970, 1971; Textoris and Dennison, 1970). The Route 70 section is the southernmost Tioga section known; to the southwest this horizon is missing because of pre-Chattanooga unconformity. The volcanic source was probably located in the central Virginia Piedmont in the latitude of Charlottesville.

The basal foot of Chattanooga shaly strata (unit 51 of Appendix) contains Plicoplasia, Eodevonaria and Leptocoelia flabellites, which suggests a Schoharie (early Onesquethaw) age for this leached silty bed. It is too weathered to ascertain whether Tioga tuffaceous admixture occurs in unit 51. The grayish black shales of units 52 and 53 lack definite Tioga tuffaceous admixture and resemble typical Chattanooga Shale higher in the section. Units 54-67 contain definite Tioga admixture, either as distinct tuff beds or as shale which weathers to brownish gray sheets containing a characteristic Tioga zone fauna of Leiorhynchus limitare, Styliolina fissurella, Tentaculites gracilistraiatus, and Ambocoelia. The Schizobolus noted in unit 58 is common in basal Millboro Shale of Virginia, but is a bit unusual for the Tioga assemblage. Orientations of hundreds of fossils on shaly slabs of unit 58 were measured, and transporting bottom current moving toward N63°W was indicated (Jones and Dennison, 1970, p. 648).

Harris and Miller (1958) reported three inches of bentonite in the lower 100 feet of dark shale in the Duffield Quadrangle 17 miles northeast of Route 70. Field examination in the Duffield Quadrangle by Dennison and Harris indicates that the bentonite recorded by Harris and Miller is the Tioga Bentonite rather than the Center Hill bentonite (Conant and Swanson, 1961, p. 30) which occurs near the middle of the Chattanooga Shale in central Tennessee. The Center Hill bentonite was not recognized in the Chattanooga Shale along Route 70; it is unknown outside the Highland Rim region in Tennessee.

The basal Chattanooga is commonly considered Late Devonian in age throughout Tennessee (Conant and Swanson, 1961, p. 12), but at Big Stone Gap in southwest Virginia the Chattanooga may extend down into Middle Devonian (Roen, Miller, and Huddle, 1964, p. B47; Oliver and others, 1967, p. 1006). Apparently the Millboro Shale (Butts, 1940, p. 308-317) merges with the basal Chattanooga Shale near the Virginia-Tennessee boundary, but farther southwest the pre-Frasnian Chattanooga was omitted as the seas trangressed westward and inundated the Devonian-age Nashville Dome. The lower portion of the dark shale at Route 70 is the oldest Chattanooga Shale in Tennessee.

In New York and elsewhere the very common criccoconarid Styliolina became extinct by early in the Cassadaga Age, in the Late Devonian (Cooper and others, 1942, Pl. 1). At Route 70, Styliolina ranges through units of the Chattanooga Formation. The poorly exposed siltstones in the lower portion of unit 93 might also be properly included in a Brallier Member.

Unit 94 at Route 70 provides a glimpse of the black shale lithology which overlies the silty Chattanooga beds. The upper black shale member is only partially exposed. In an unpublished dissertation Sanders (1952) designated the lower black shale, middle siltstone, and upper black shale respectively as three new stratigraphic names: Little War Gap Shale (about 500 feet thick), Klepper School formation (800 feet thick at old Klepper School, now Klepper Chapel, at Route 70), and Salt Lick Gap Shale (25 feet thick). These names have no formal status because they were never published and because no detailed measured section of the type section is given. The present authors do not wish to give Sanders' names formal acceptance, at least not until more regional stratigraphic work is done. The upper black shale (Salt Lick Gap Shale) portion of the Chattanooga at Route 70 is probably the same as the Big Stone Gap Shale Member of the Chattanooga (Swartz, 1927, p. 494-495), which is considered latest Devonian and earliest Mississippian in age (Roen, Miller and Huddle, 1964; Oliver and others, 1967, 1969). If this interpretation is correct, the top of the Chattanooga is at the top of the Devonian System or slightly higher, with no unconformity between it and the overlying Grainger Formation. The Devonian System extends at least to unit 94 of the Appendix measured section, and perhaps all the way up to the base of the Grainger Formation. The rocks near the systemic boundary contain no visible fossils, but they should be searched for conodonts as the best means of precisely fixing the position of the systemic boundary.

MISSISSIPPIAN SYSTEM

The base of the definite Mississippian System is represented by the basal beds of the Grainger Formation (Keith, 1895, p. 74, Pl. 1; 1896) named for Grainger County, Tennessee, where the Formation is exposed in the same strike belt as the Route 70 section. The Grainger consists of "bluish, greenish, and brownish argillaceous shale, sandy shale, sandy siltstone and generally silty and thin-bedded sandstone" (Rodgers, 1953, p. 106-107).

Kenneth O. Hasson recently completed (1971) a dissertation at the University of Tennessee on the stratigraphy of the Grainger Formation in much of eastern Tennessee. The lower boundary of the Grainger Formation in our section is placed to be consistent with Hasson's interpretation and criteria (field conference by Dennison and Hasson, 1972). Hasson (1973) has published descriptions of a type section and a reference section of the Grainger Formation along Clinch Mountain at U. S. Route 25-E and Tennessee Route 33, respectively.

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APPENDIX: MEASURED SECTION

Section is located in Hawkins County, Tennessee, in cuts along Tennessee Route 70 between crest of Clinch Mountain at Little War Gap and gap through Pine Mountain. Located in Pressmens Home (171-NE) and Kyles Ford (170-SE) 7.5-minute topographic quadrangles; latitude 36°30'N; longitude 83°1'W. Primary thickness control was by plane table with detailed measurements by tape. Stratigraphic details measured during 1966-69 and 1972 by John M. Dennison, aided in field at various times by Arthur J. Boucot, Michael L. Jones, Thomas G. Beaman, and Kenneth O. Hasson. Units 92-113 are from the dissertation by Hasson (1972, p. 101-102) with slight clarification based on field conference between Dennison and Hasson.

	Feet
MISSISSIPPIAN SYSTEM	
Grainger Formation (367 feet total; Hasson, 1972, p. 100-101). (Units 104-113 are 59.4 feet thick.)	
113. Shale, silty, light olive gray.	1.5
Basal siltstone member (57.9 feet) (Units 104-112)	
112. Conglomerate, quartz pebble.	1.4
111. Siltstone, light olive gray.	1.5
110. Siltstone, very thickly bedded, essentially a single bed, with conglomerate stringer near center; weathers light olive gray with tinge of grayish red.	10.5
109. Siltstone, thickly bedded, as in unit 110.	3.0
108. Siltstone, thickly to very thickly bedded, weathers grayish red.	18.5
107. Siltstone, thinly to mediumly bedded.	5.0
106. Siltstone, mediumly to thickly bedded.	3.0
105. Siltstone and shale. Shale is medium dark gray, thickly laminated, weathers light olive gray and chippy; individual siltstone beds up to 0.3 foot thick, but rapidly pinch out laterally.	5.0
104. Siltstone, mediumly to thickly bedded, bedding not very distinct; some parts weather grayish red.	10.0
DEVONIAN SYSTEM (2,155 feet; units 45-103.) (Possibly as thin as 2,091 feet; units 45-94.)	
Chattanooga Shale (2,138 feet; units 51-103.) (At least 2,073 feet thick; units 51-94.)	
103. Siltstone and shale, interbedded. Siltstones are about 0.2 foot thick and pinch out rapidly; shale is silty, medium dark gray, thickly laminated, weathers to large plates and chips.	14.5
Units 95-103 are transitional beds between Chattanooga and Grainger Formations, but are assigned to the Chattanooga to be consistent with the base of the Grainger Formation in the type section designated by Hasson (1973) and traced by Hasson (1972) along the Clinch Mountain outcrop belt. Hasson (1972, p. 102) assigned these units 94-103 to the Big Stone Gap Member of the Chattanooga Shale. Unit 94 is approximate position of Salt Lick Gap shale member named informally by Sanders (1952).	
102. Shale, silty, medium dark gray, thickly laminated, weathers light olive gray and chippy. A few thin siltstones are interbedded.	9.0
101. Shale, thickly laminated, weathers light olive gray and chippy; interbedded siltstones mostly 0.05-0.1 foot thick.	8.0
100. Siltstone, single bed.	1.5
99. Shale, thickly laminated, weathers light olive gray and chippy;	

interbedded siltstones 0. 05-0. 1 foot thick comprise about 20 percent; a few limonite nodules also in interval. 15. 0

98. Siltstone, mediumly bedded, weathers light olive gray. 2. 5

97. Siltstone, calcitic, medium dark gray, contains fossil fragments. 0. 8

96. Shale, thickly laminated, weathers light olive gray and chippy; some very thin siltstone beds in interval. 5. 5

95. Shale, thickly laminated, weathers light olive gray and chippy; a few thin siltstone beds in interval. Base of exposure along highway cut. 7. 5

94. Covered. A few chips of shale, very dark gray to grayish black, are exposed in unknown thickness in diggings for telephone pole guy wire located at stratigraphic position of base of this unit. Thickness of shale projected from exposure on side of Pine Mountain. 59

Hasson (1972, p. 102-103) assigns units 76-93 to Klepper School Member named informally by Sanders (1952). Units 76-93 total 1,074 feet in thickness. Units 78 to lower part of 93 include siltstones which characterize Brallier Formation in Virginia, and they are considered to be a tongue of Brallier Formation extending into Tennessee. The Brallier tongue of units 78-93 totals 709 feet in thickness.

93. Covered. A few patches of shale are exposed in stream bed on southeast side of road; shale is thickly laminated and weathers light olive gray. Base of this interval is approximate position of siltstones in bank of stream at base of Pine Mountain. 183

92. Covered. No topographic indication of resistant beds. 142

91. Shale, silty, dark gray, thinly to thickly laminated, weathers platy to chippy. 27. 0

90. Covered. 107

89. Siltstone, thickly laminated within thin beds, weathers light olive gray and blocky to lumpy. Forms upper knobs of topographic influence of silty strata (tongue of Brallier Formation lithology). 42

88. Shale, very dark gray, thinly laminated with some thickly laminated. 26

87. Shale, dark gray, thinly to thickly laminated, weathers light olive gray and chippy; with 17 distinctly bounded beds of siltstone 0.03-0. 10 foot thick scattered throughout. (Tongue of Brallier Formation influence in Chattanooga Shale.) 102

86. Shale, dark to very dark gray, thinly to thickly laminated, weathers yellowish gray and chippy to platy. 30

85. Shale, silty, dark gray, thickly laminated, weathers yellowish gray to light olive gray and chippy. 12

84. Siltstone, fairly distinct bed, weathers yellowish gray. 0. 05

83. Shale, silty, dark gray, thickly laminated, weathers light olive gray to yellowish gray and chippy. 18

82. Siltstone, thickly laminated and shaly in appearance, almost platy, weathers yellowish gray. 3. 0

81. Shale, silty, probably dark gray when fresh, thickly laminated, weathers yellowish gray and chippy. 14. 0

80. Siltstone, fairly distinct bed, weathers yellowish gray. 0. 1

79. Shale, silty, thickly laminated, weathers yellowish gray and chippy. 3. 0

78. Siltstone, distinct bed, weathers yellowish gray. Units 78-84 hold up lower knob of Brallier topographic influence. 0. 2

Units 51-77 correspond to Millboro Shale of Virginia usage, if units 78-93 correspond to Brallier Formation of Virginia. Units 51-77 total 1,305 feet in thickness.

77. Shale, silty in part, dark gray, thinly to thickly laminated, weathers yellowish gray and chippy to platy. 33
76. Covered. 332

Units 51-75 correspond to Little War Gap shale member as informally proposed by Sanders (1952). Units 51-75 total 940 feet in thickness.

75. Shale, bottom half is grayish black to black, top half is very dark gray to grayish black, all is thinly laminated; weathers yellowish gray and platy; unfossiliferous. 180
74. Shale, grayish black, thinly laminated, fairly soft and weak, weathers yellowish gray and platy; unfossiliferous. Top is at mailbox along highway. 148
73. Covered, except for some scattered exposures of black shale along highway. 350
72. Shale, black, thinly laminated, weathers yellowish gray and platy; some drag folding. 50
71. Covered. Section offset along highway nearly along strike. Thickness obtained by plane table survey. 100
70. Shale, grayish black, thinly laminated. No fossils found in unit. 7
69. Shale, black to very dark gray, mostly grayish black, thinly laminated, weathers yellowish gray and platy. Styliolina occurs in basal 70 feet, becoming very rare in upper part of that interval. Top of unit is 7 feet above highest recorded occurrence of Styliolina. 77
68. Shale, grayish black, thinly laminated, drag-folded and disharmonic with straight bedding of underlying strata. 0.8
67. Siltstone, with Tioga Bentonite mica, light brownish gray. Top Tioga tuffaceous layer. (Tioga tuffaceous admixture ranges through at least 22 and perhaps 27 feet of strata; units 51-67.) 0.10
66. Shale, grayish black, drag-folded. 0.3
65. Siltstone, with Tioga Bentonite mica, light brownish gray. 0.05
64. Shale, grayish black, thinly laminated. 2.1
63. Shale, thickly laminated, looks like very fine Tioga mica siltstone which has been leached. 0.1
62. Shale, grayish black, thinly laminated. 1.5
61. Siltstone, Tioga micaceous bed, weathers yellowish gray. 0.09
60. Shale, grayish black, thinly laminated, especially pyritic in top 1.6 feet. 11.6
59. Siltstone to silty shale, yellowish gray; Tioga Bentonite micaceous bed. 0.13
58. Shale, very dark gray with slight brownish color, thinly laminated; probably slightly tuffaceous; abundant Leiorhynchus limitare, Styliolina fissurella, Tentaculites gracilistriatus, Ambocoelia, and Schizobolus. Samples collected for fossil orientation studies (Jones and Dennison, 1970). 0.8
57. Shale, brownish black, pyritic, with Tioga tuffaceous admixture. 0.2
56. Shale, grayish black, thinly laminated, with slight fracture cleavage. 4.9
55. Shale, medium gray, thickly laminated. (Very leached Tioga Bentonite tuffaceous layer?) 0.2
54. Shale, brownish gray, with Ambocoelia and other fossils of Tioga zone. 0.1

53. Shale, grayish black, thinly laminated, weathers platy; drag-folded and slickensided. May have Tioga tuffaceous admixture, but not obvious. 4.0

52. Shale, grayish black, thinly laminated, some is quite stiff and seems siliceous. Weathered exposures contain white powdery mineral, probably basaluminite. This unit of very leached strata may contain slight Tioga tuffaceous admixture. 0.3

51. Clay, silty, very leached and weathered; very pyritic with sulfurous odor; some glauconite when fresh; dark gray with some brownish gray. Very deeply weathered top part may represent a coarse mica layer of Tioga Bentonite weathered beyond definite recognition. Abundant fauna suggests Schoharie (early Onesquethaw) age: Plicoplasia, Eodevonaria, Leptocoelia flabellites, spiriferid brachiopod. (This unit was also collected earlier by Boucot and Harris for U. S. Geological Survey studies reported by Harris and Miller, 1958.) Unit included with Chattanooga Shale because of its dark, argillaceous character. 1.1

Wildcat Valley Sandstone (17.3 feet.) (Units 45-50.)

Huntersville Member (7.9 feet.) (Units 49-50.)

50. Sandstone, fine, thinly to mediumly bedded, with irregular beds, weathers grayish orange. Phosphate nodules, grayish black, and weathering light gray, are up to 3 inches in diameter and are common 0.0-2.1 and 4.5 feet above base of unit, and scattered 6.2 feet above base. Fauna 4.6-5.6 feet above base contains Pentamerella, Plicanoplia, Fimbrispirifer, Pentagonia, Leptocoelia flabellites, Acrospirifer, Cyrtina, Coelospira cf. camilla, Craniops, Meristella, Leptaena "rhomboidalis", Chonostrophia?, rensselaerid (Amphigenia?), rhynchonellid, Conocardium. 7.0

49. Sandstone, medium to coarse, thinly to very thinly bedded, weathers grayish orange. Top surface has phosphate nodules. Assigned to Huntersville Member because of thin bedding. Probably represents reworked Oriskany. 0.9

Oriskany Member (9.4 feet.) (Units 45-58.)

48. Sandstone, quartzose, coarse, thickly bedded, friable, weathers dark yellowish orange. Quartz granules 2.1 feet above base. Probable disconformity at top. 5.4

47. Sandstone, quartzose, medium to coarse, friable, weathers moderate yellowish brown. Extensive bedding surface exposure contains abundant large fossils: Costispirifer arenosus, Dalejina musculosa, Rensselaeria, Edriocrinus sacculus, Meristella. Basal 0.5 foot is most fossiliferous. 2.0

46. Sandstone, quartzose, coarse, fairly massive, weathers moderate yellowish brown. 1.0

45. Sandstone, quartzose, conglomeratic with rounded quartz pebbles up to an inch long, weathers moderate yellowish brown to dark yellowish brown. Contains Costispirifer. Paraconformity at base exhibits no relief. 1.0

SILURIAN SYSTEM (311 feet.) (Units 8-44.)

Clinch Sandstone (311 feet.) (Units 8-44.)

Upper member (42.4 feet) (Probably intertonguing from west of siltstone and sandstone lithology of Rockwood Formation.) (Units 31-44.)

44. Siltstone, yellowish gray, thickly laminated to thinly bedded, ripple-marked. 2.8

43. Sandstone, very fine- to medium-grained, yellowish gray, ripple-marked, cross-bedded; some layers contain siltstone chips up to an inch in diameter . Section offset along highway at base of this unit, with probably no omission of stratigraphic thickness.	3.7
42. Sandstone, fine, appears slightly greenish (glauconitic?).	2.0
41. Sandstone, fine, yellowish gray.	2.0
40. Siltstone, yellowish gray, thickly laminated.	4.0
39. Sandstone, fine, yellowish gray.	2.5
38. Siltstone, yellowish gray, thickly laminated.	4.0
37. Sandstone, fine, yellowish gray, mediumly to thickly bedded, very fractured with limonite in fractures.	3.2
36. Siltstone, yellowish gray to slightly greenish (glauconitic?), thickly laminated, weathers lumpy.	2.9
35. Sandstone, quartzose, fine, white to yellowish gray, thickly bedded.	8.2
34. Siltstone, weathers yellowish gray and lumpy to chippy.	2.1
33. Sandstone, fine, weathers yellowish brown; top half appears hematitic.	0.5
32. Siltstone, thickly laminated, weathers yellowish gray.	2.2
31. Shale, thickly laminated, weathers light olive gray to yellowish gray and chippy.	2.3
Lower massive member (269 feet.) (Units 8-30.)	
30. Sandstone, quartzose, fine, yellowish gray to white, thick-bedded. This unit is top massive sandstone in high cut at highway switchback.	16
29. Siltstone, yellowish gray, lenticular.	0.4
28. Sandstone, quartzose, fine, yellowish gray to white, thick-bedded, cross-bedded with eastern source; oscillation ripples on top surface.	6.6
27. Siltstone, yellowish gray, lenticular.	0.5
26. Sandstone, quartzose, fine, yellowish gray to white.	3.6
25. Siltstone, yellowish gray, lenticular.	1.2
24. Sandstone, quartzose, fine, yellowish gray to white, thick-bedded; contains Arthrophycus and Skolithos, trails and burrows on bedding surface up to 1 cm diameter and a meter long, interference ripples and desiccation cracks. Unit probably represents a beach deposit. Section is offset along strike, matching this unit.	14
23. Sandstone, quartzose, fine- to medium-grained, yellowish gray to white, cross-bedded with eastern source.	5
22. Sandstone, quartzose, fine, white to yellowish gray, very thick- to thick-bedded.	93
21. Sandstone, quartzose, fine, white to yellowish gray, cross-bedded with generally eastern source.	4.0
20. Sandstone, quartzose, fine, white to yellowish gray, very thick- to thick-bedded; thickest bed is 17 feet thick.	22
19. Conglomerate, composed of quartz pebbles to 10 mm diameter, white.	0.3
18. Sandstone, quartzose, fine- to coarse-grained, conglomeratic with scattered quartz pebbles to 3 mm diameter, white.	2.0
17. Sandstone, quartzose, mostly fine-grained, white to yellowish gray, thick- to very thick-bedded.	13
16. Sandstone, quartzose, coarse to conglomeratic, with scattered quartz pebbles to 16 mm diameter, but mostly 3-4 mm diameter; white.	2.0

15. Sandstone, quartzose, fine- to medium-grained, white with some yellowish gray, thick-bedded with some medium-bedded. 50

14. Sandstone, quartzose, coarse-grained with quartz pebbles to 14 mm diameter, but mostly 3-5 mm diameter; white. At highway sign indicating curves ahead. 1.0

13. Sandstone, quartzose, fine- to medium-grained, white with some yellowish gray, thick- to medium-bedded. 16.0

12. Covered. 2.0

11. Sandstone, quartzose, fine, white. 1.0

10. Covered. 3.0

9. Sandstone, quartzose, medium- to coarse-grained and conglomeratic with quartz pebbles up to 8 mm diameter; white. 3.0

8. Sandstone, quartzose, fine- to medium-grained, white to yellowish gray, in beds up to 1.5 feet thick. 9

ORDOVICIAN SYSTEM (27+ feet.) (Units 1-7.)

Juniata Formation (about 400 feet total thickness, with abrupt top and gradational basal contact.) (Units 1-7.)

7. Shale, thickly laminated; basal half is grayish red, top half weathers light olive gray. Entire shale unit is arbitrarily included in Juniata Formation. Units 1-7 are best exposed northeast of highway beside house. 3.0

6. Sandstone, quartzose, fine, yellowish gray to white, in beds 0.5-1.2 feet thick. 4.0

5. Shale, thickly laminated, weathers light olive gray and chippy. 1.7

4. Shale, grayish red, weathers chippy to lumpy. 1.6

3. Sandstone, fine, yellowish gray, in single bed. 1.9

2. Shale to mudstone, grayish red. 15

1. Shale to mudstone, grayish red with greenish mottling. Not measured

AGE OF SWAMPS IN THE ALCOVY RIVER DRAINAGE BASIN

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ABSTRACT

Six samples of organic materials taken at depths of 1.6 ft. to 13.3 ft. below the swamps on the flood plains that comprise the Alcovy River Drainage Basin in Georgia have C^{14} dates that range from 1785 A.D. to 6750 B.C. European colonization and agricultural activity on the Georgia Piedmont began about 1814. Since the swamp sediments predate European colonization, it is concluded that the Alcovy River swamps were caused by natural processes rather than soil wash from agricultural activity.

INTRODUCTION

The Alcovy River drainage basin is located within Gwinnett, Walton and Newton Counties, Georgia, about 30 miles east of Atlanta (Figure 1). The purpose of this paper is to report some observations on the nature and age of the numerous riverine swamps that are found along the course of the Alcovy River and several of its tributaries. Narrow swamps occur at intervals along the streams and within the flood plain of the Alcovy and its tributaries. The downstream ends of these swamps have been observed to coincide with exposures of bedrock that cross the streams and produce shoals or rapids. These rock barriers presumably define positions of knickpoints along the streams. Swamps develop upstream from rock barriers as a result of locally lower gradients. Trimble (1970) has postulated that these swamps are the result of accelerated erosion caused by agricultural activity and resultant choking of the streams with this erosional debris. To test

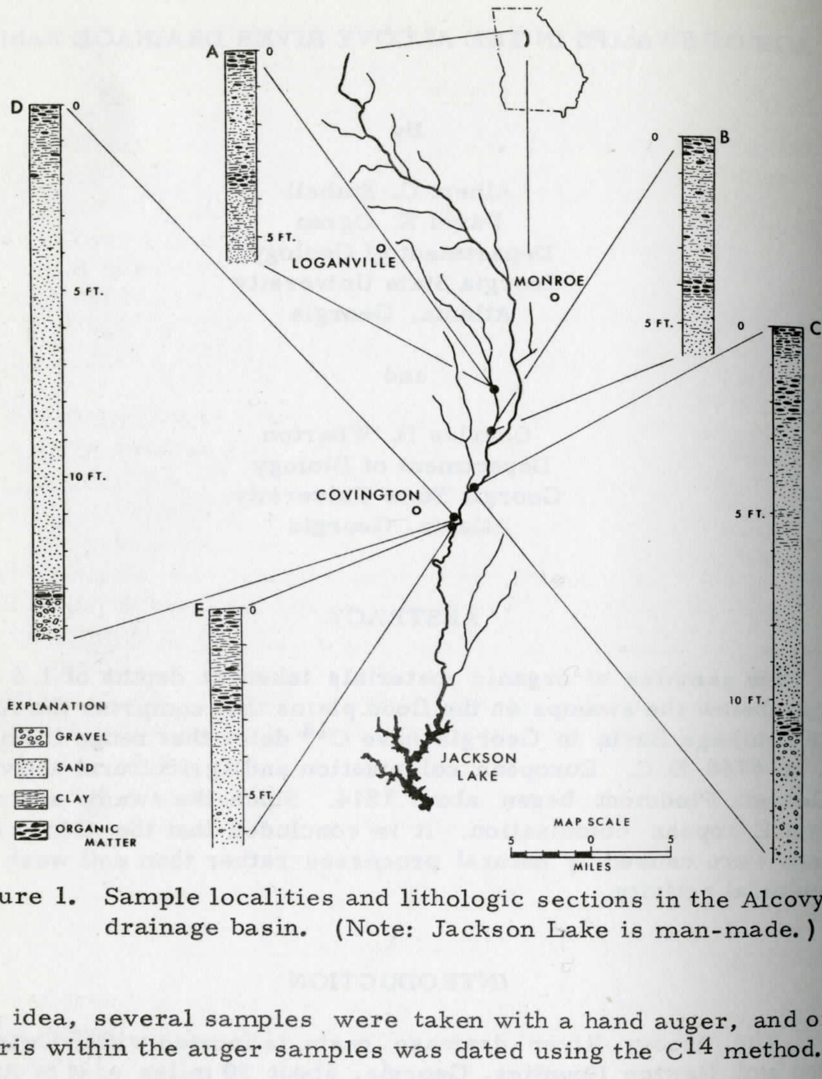

Figure 1. Sample localities and lithologic sections in the Alcovy River drainage basin. (Note: Jackson Lake is man-made.)

this idea, several samples were taken with a hand auger, and organic debris within the auger samples was dated using the C^{14} method.

Acknowledgments

We thank the Georgia Conservancy, Atlanta, Georgia, for funding the C^{14} dates. Samples were analyzed by John Nokes and Betty Lee Brandau of the Geochronology Laboratory, University of Georgia, Athens, Georgia.

DESCRIPTION AND AGE OF SEDIMENTS

Sediment types encountered in the auger samples include gravelly sands, coarse to fine micaceous quartz sands, sandy clays and clay. The distribution of these sediment types is shown in the sections

Table 1

Location	Depth	Age
A	3.5 ft.	645 $\pm$ 225 B. P. (Circa 1305 A. D.)
B	4.0 ft.	465 $\pm$ 80 B. P. (Circa 1485 A. D.)
C	1.6 ft.	165 $\pm$ 105 B. P. (Circa 1785 A. D.)
C	10.9 ft.	1825 $\pm$ 120 B. P. (Circa 125 A. D.)
D	13.3 ft.	8700 $\pm$ 520 B. P. (Circa 6750 B. C.)
E	2.3 ft.	400 $\pm$ 75 B. P. (Circa 1550 A. D.)

included in Figure 1. Sufficient organic matter was obtained from some samples to permit C^{14} dating. Organic matter was particularly abundant in certain of the clay units and in some of the gravelly sands.

As summarized in Table 1, the ages of the sediments range from about 165 years B. P. to 8700 years B. P. Referring to section C, the sediment 1.6 feet below the surface was deposited about 1785 A. D., while sediment 10.9 feet below the surface was deposited about 125 A. D. Other samples obtained from near the present surface (2.3 feet to 4.0 feet below the surface) were deposited from about 1550 A. D. to 1485 A. D.

CONCLUSIONS

As evidenced by these C^{14} dates, very little sediment has been deposited at the sample localities since the advent of European settlement. Settlement began about 1814 according to Trimble (1970, p. 131). The deposition of 9.3 feet of sediment in 1660 years (see section C) does not appear to constitute evidence of an accelerated rate of deposition, but seems to be a natural rate for a river floodplain - swamp environment. The thin layer of sediment deposited since 1785 A. D. (section C) supports the idea that no abnormally large amounts of erosional debris have entered the Alcovy drainage basin since the beginning of agricultural activity in this area. We therefore conclude that the Alcovy drainage basin and its numerous swamps are the result of entirely normal geological processes and significantly predate the arrival of agriculturally active Europeans in this area.

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THE DISTRIBUTION OF CHEILOSTOME BRYOZOA IN A TIDAL CREEK SYSTEM ON THE SOUTH CAROLINA COAST

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ABSTRACT

The distribution of Cheilostome Bryozoa in a tidal creek system on the South Carolina coast was analyzed to determine the potential usefulness of these animals as environmental indicators. The diversity of the species present decreases away from the ocean, whereas the relative density is greater in an area intermediate between the heads of the creeks and the ocean. Q-mode cluster analysis of these data establishes three associations of stations that are interpreted as three distinct environments. Each environment is characterized by a particular assemblage of bryozoans.

INTRODUCTION

The Cheilostome Bryozoa have been abundant in the seas of the world since the Cretaceous Period, and their calcareous skeletons are major constituents of various marine deposits.

Although there has been marked progress in bryozoology in the last few years, it is not as advanced a field as malacology. Some aspects of bryozoology are comparatively neglected; and, beyond the work of Cheetham (1963), Lagaaij and Gautier (1965), Osborn (1944), Rucker (1967) and the summaries of Schopf (1969) and Cuffey (1970), little attention has been paid to the potential utility of Bryozoa as environmental indicators. In this study, the occurrence and distribution of Bryozoa in a tidal creek system on the South Carolina Coast is described, and species diversity and relative density are shown to be related to the changing environment along the creek system.

Acknowledgments

The authors wish to acknowledge the financial support of the Belle W. Baruch Foundation for the research. F. John Vernberg reviewed and discussed the manuscript but the authors assume full responsibility for the conclusions.

AREA OF STUDY

The southern two-thirds of the South Carolina coastline consists of a series of barrier islands usually separated from the mainland by several kilometers of tidal marsh. Branching tidal channels connect with the sea by way of tidal inlets within the marsh. Marine waters drain and flood the channels through these inlets largely in response to a semi-diurnal tide.

The North Inlet area is a marsh system approximately four kilometers long and one and one-half kilometers wide (Figure 1). The marsh is bounded to the west by the mainland and to the east by two barrier islands separated by the North Inlet tidal channel. The elevation of the marsh surface is between mean sea level and the high spring tide level. The normal tidal range is 1. 37 meters. The tidal creeks have a total length of approximately four kilometers while their widths vary from three or four meters at the head of Debidue Creek to over two hundred meters at their mouths. The creeks vary in depth from approximately seven meters at the mouths to less than one meter at the heads of the tributary creeks.

ENVIRONMENT OF STUDY

Two separate creek systems have been examined in the North Inlet marsh (Figure 2). Debidue Creek is connected to North Inlet at its landward extremity. The Town Creek system also connects with North Inlet at its seaward end, but its other termination enters into a shallow system of bays which connects with Winyah Bay, the lower estuary of the Pee Dee and Black Rivers.

Salinity

The water in Debidue Creek is primarily North Atlantic water which enters and exits in response to tidal forces and exhibits no systematic semidiurnal salinity fluctuation. However, immediately following periods of very heavy rain, reduced salinities ($7^{o}/00$-$10^{o}/00$) have been measured in Debidue Creek (H. Freeman and N. Chamberlain, personal communication, 1971). Periods of reduced salinities are only ofvery short duration because of the tidal exchange of water, and normal

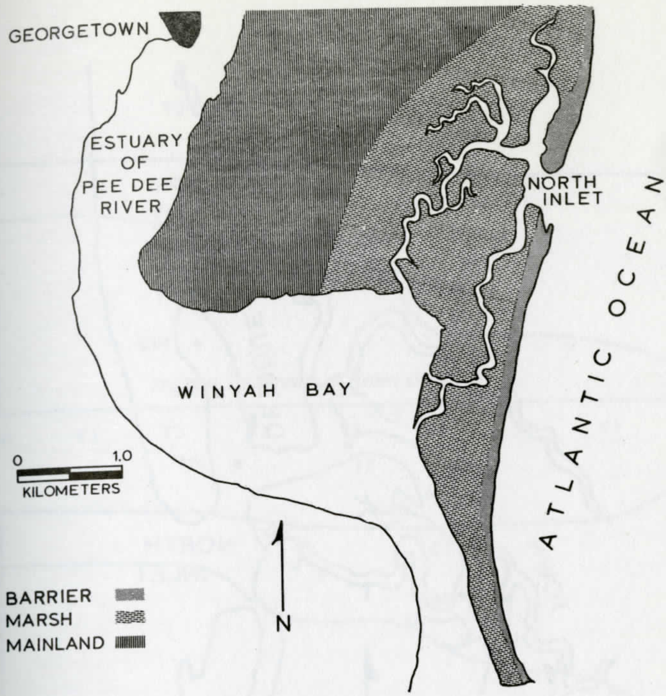

Figure 1. Location of study area.

salinities (32°/00-35°oo) are swiftly reestablished.

In contrast, systematic salinity changes related to tidal events can be measured in Town Creek. During the period of ebb tide, low salinity water from Winyah Bay enters Town Creek and a salinity gradient is established for a short period. During flood tides shelf water progressively flushes through Town Creek into Winyah Bay and salinities of 32°/oo-35°/oo can be measured throughout Town Creek. However, the salinities are very variable since the degree of influence of Winyah-Bay water and North-Inlet-derived water on Town Creek depends on many tidal and atmospheric variables, both local and within the Pee Dee River drainage basin.

In summary, Town Creek exhibits considerable short-term salinity fluctuations and variability, and a salinity gradient from marine to fresh water conditions can be measured along it. In contrast, Debidue Creek water is normally at shelf water salinities (32-35°/oo) although short-duration periods of reduced salinity occasionaly occur after periods of heavy rain.

Salinity and temperature measurements were made throughout the study year (1970) by the authors and a number of other Baruch Coastal Institute investigators. The range of salinities recorded at the sample stations in the two creeks are described in Figures 3a and 3b. Most measurements were made at mean low water.

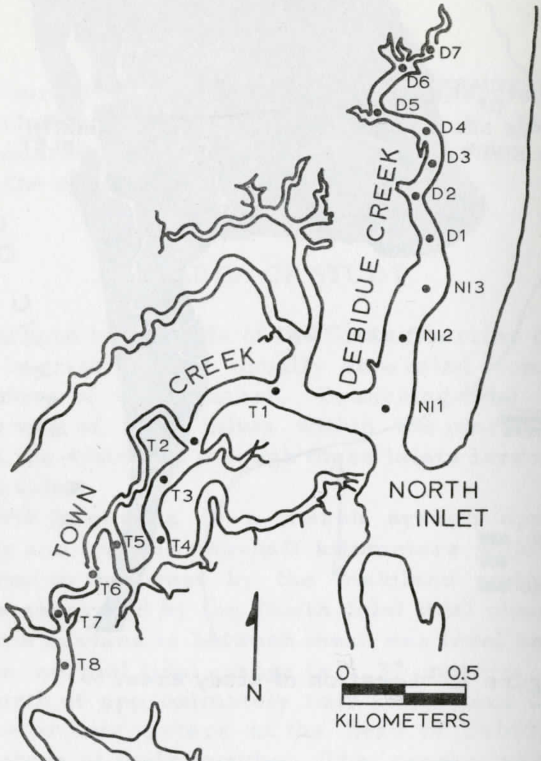

Figure 2. Location of sample stations in North Inlet (NI), Town Creek (T), and Debidue Creek (D). Samples are numbered consecutively from the sea into the creek system.

Temperature

The water temperature in the tidal creek system varies seasonally in a manner typical for this coast region. A series of temperature curves are shown in Figure 3c for the North Inlet area (the measurements are monthly averages for water at 1/2 meter above the bottom surface at mean low tide). At the heads of the creeks where the channels are shallow, air temperature has a greater effect on bottom water temperature, and this may be seen in the more extreme values for the headwaters of Debidue and Town Creeks.

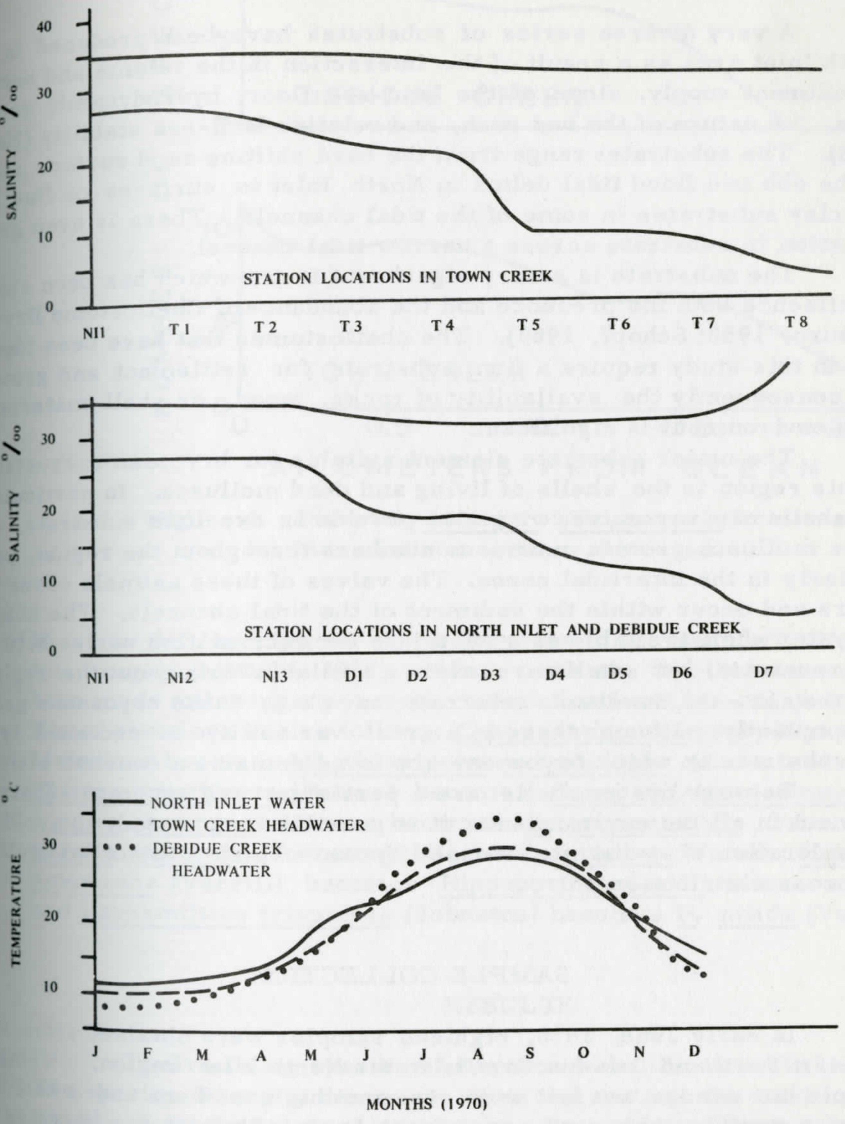

Figure 3. The range of salinity measurements made in Town and Debidue Creeks (3a and b), in 1970, and the average monthly bottom water temperature (3c) in the North Inlet tidal creek system. The maximum and minimum salinities are indicated for various sample stations in Town and Debidue Creeks. The salinity in Debidue Creek is normally close to the maximum salinity measured and only occasional very short term reductions in salinity were measured.

Substrate

A very diverse series of substrates have been produced in the North Inlet area as a result of the interaction in the volume and nature of sediment supply, slope of the land-sea floor, hydrodynamic conditions, the nature of the bed rock, and relative land-sea stability (Hoyt, 1968). The substrates range from the hard shifting sand surface found on the ebb and flood tidal deltas in North Inlet to surfaces on fine silt and clay substrates in some of the tidal channels. There is even great variation in substrate across a narrow tidal channel.

The substrate is a very significant factor which has been shown to influence both the presence and the abundance of Cheilostome Bryozoa (Maturo, 1958; Schopf, 1969). The cheilostomes that have been identified in this study require a firm substrate for settlement and growth, and consequently the availability of rocks, wood, or shell material in each environment is significant.

The major substrate element suitable for bryozoan encrustation in this region is the shells of living and dead molluscs. In particular, the shells of Crassostrea virginica provide an excellent substrate, and these molluscs grow in enormous numbers throughout the region, particularly in the intertidal zones. The valves of these animals cover the floors and occur within the sediment of the tidal channels. The amount of oyster shell available as a substrate for encrustation varies between environments, but shells are always available throughout the region, and they are the dominant substrate on which these bryozoans grow. Consequently, although there is a great variability in sediment type, the substrate on which bryozoans are found remains a constant element.

Because oyster shells are a persistant and common substrate element in all the environments, it is possible in this study to avoid the consideration of substrate variability as a major factor controlling bryozoan distribution.

SAMPLE COLLECTION

In early June, 1970, eighteen samples were obtained from stations in Town and Debidue Creeks in the North Inlet region. Using a simple box dredge two feet wide, one foot high, and one and a half foot deep, a sample volume of approximately 3 cubic feet was obtained by single or multiple tows at each station. The dredge was closed with a screen having a mesh size of 0.63 cm. The sample was very carefully searched for living Cheilostome species with the aid of a dissecting microscrope.

Taxonomy

The classification followed in the identification of species is

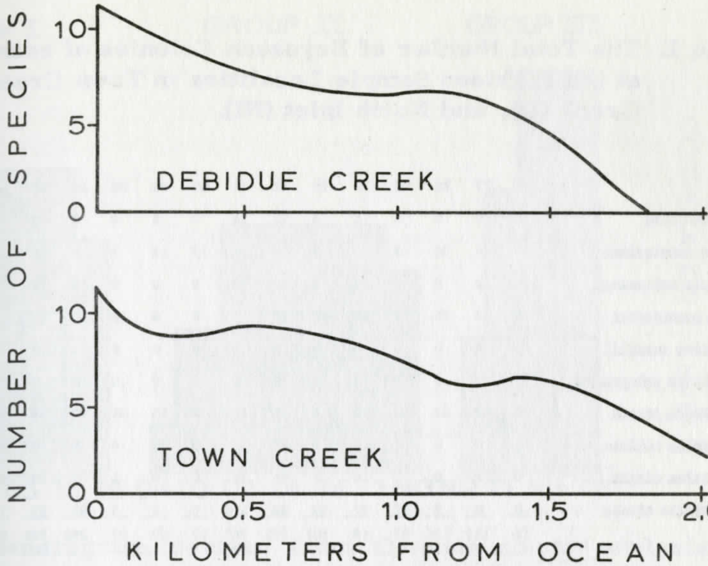

Figure 4. Diversity pattern of Bryozoan species as a function of distance from the ocean.

based on the descriptions of the Bryozoa of the Beaufort, North Carolina, region (Maturo, 1957). Some revisions to that taxonomy have been made following a personal communication from Maturo (1971). These revisions are as follows: Conopeum commensale Kirkpatrick and Metzelaar becomes Membranipora arborescens (Canu and Bassler); Electra crustulenta (Pallas) becomes Conopeum tenuissimum (Canu); Electra hastingsae Marcus becomes E. monostachys Osburn; Schizoporella unicornis (Johnston) becomes S. errata Waters; Hippodiplosia americana (Verrill) becomes Hippoporina verrilli Maturo and Schopf; and Parasmittina trispinosa (Johnston) becomes P. nitida (Verrill).

RESULTS

Twelve living species of Bryozoa were identified in the samples. The species diversity decreases from the sea into the tidal creeks (Figure 4). A total of eleven species was recorded in North Inlet with the number decreasing to a single species living at the head of Debidue Creek, and three species at the head of Town Creek.

Two species, Thallamoporella falcifera and Membranipora tuberculata, attach to the floating algae Sargassum. They are introduced into the North Inlet tidal creek system in an intermittent fashion, and consequently they are not used in the succeeding calculations and discussion of the Bryozoa which attached to the in situ substrate. The number of colonies of the eighteen stations is listed in Table 1. This

Table 1. The Total Number of Bryozoan Colonies of each Species Found at the Eighteen Sample Localities in Town Creek (T), Debidue Creek (D), and North Inlet (NI).

	T8	T7	T6	T5	T4	T3	T2	T1	D7	D6	D5	D4	D3	D2	D1	NI3	NI2	NI1
Bugula neritina	0	0	0	0	1	8	12	14	0	0	0	0	0	0	0	5	6	0
Conopeum tenuissimum	10	44	38	12	0	0	0	0	17	11	3	0	0	0	0	0	0	0
Cryptosula pallasiana	0	0	0	0	0	0	2	3	0	0	0	5	7	1	5	3	26	16
Electra monostachys	1	6	26	12	15	23	10	7	0	6	18	23	44	8	9	19	48	82
Hippoporina verrilli	0	0	0	0	0	0	1	5	0	0	0	0	0	0	0	0	2	5
Membranipora arborescens	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	8	2
Membranipora tenuis	1	61	69	40	10	22	50	61	0	13	31	99	55	20	22	60	62	42
Microporella ciliata	0	0	0	0	0	2	28	51	0	0	0	0	0	1	4	0	12	11
Parasmittina nitida	0	0	0	2	6	22	64	78	0	0	1	31	20	20	19	7	28	15
Schizoporella errata	0	0	3	17	37	30	34	116	0	0	4	97	95	37	25	10	12	9
	12	111	136	83	69	101	201	342	17	30	57	250	221	87	84	105	204	182

basic data was used to determine the degree of association of each sample to every other sample using the statistical techniques described below.

The contribution of the number of colonies of each species was initially expressed as a percentage of the total number of bryozoan colonies collected at each locality. After careful consideration of the percentage data matrix the percentage values were scaled values, Pearson's Product Moment correlation coefficients were calculated between the samples to produce a Q-mode correlation matrix. The correlation matrix was clustered using the unweighed pair group method described by Sokal and Sneath (1963). The results are presented in the cluster diagram (Figure 5) in which highly correlated stations are associated. Examples and descriptions of the technique can be found in Parks (1966), Mello and Buzas (1968), Sokal and Sneath (1963), and Hazel (1970).

Three associations of stations having similar faunal assemblages can be distinguished. The stations associated together in Group I occupy the upper extremities of Debidue and Town Creeks. Included in this group are three stations from Debidue Creek (D7, D6, D5) and four stations from Town Creek (T8, T7, T6, T5). Station D7 has been grouped with this association because of its correlation with stations D6, D5 and T8. The seven stations in Group II occupy the intermediate localities between Group I stations (the creek extremities) and North Inlet. Group II stations are mainly from Debidue Creek (D4, D3, D2, D1, but also included in Group II are stations from Town Creek (T4, T3) and one station from the northernmost section of North Inlet (NI3). Four stations, N11, N12, T2 and T1, comprise Group III, and all four are directly associated with North Inlet and the immediate waters of Town Creek.

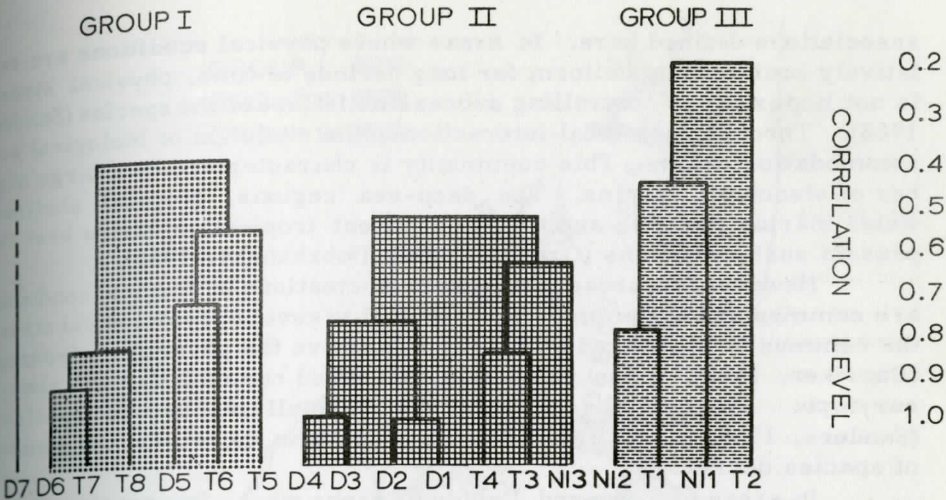

Figure 5. Dendrogram derived from Q-mode cluster analysis of the diversity and density of Bryozoan species in the sample localities.

DISCUSSION OF LIVE ASSEMBLAGE

A progressive decrease in the species diversity away from the sea is evident in the North Inlet area. In an evaluation of the comparative merits of the number of species, and the proportional division of the population into species as measures of diversity, Sanders (1968) indicated that the species number is the more valid diversity measurement. Diversity is defined here as the total number of species present at a sample station. Although this diversity pattern is similar in both creeks, each creek is unique in its physical and chemical characteristics. Town Creek, which opens into a series of low-salinity bays at its head, displays a definite salinity gradient. Debidue Creek has no connection with a fresh water drainage system and exhibits no salinity gradient; but reduced salinities were observed after very heavy rains. However, in both creeks, there is great potential variability in the amplitude of temperature and salinity fluctuations and intertidal exposure.

The diversity pattern exhibited by bryozoans in the North Inlet area is similar to faunal diversity patterns described by Wells (1961) and Bird (1970) in the Newport River Estuary. Osburn (1944) noted the occurrence of some of these bryozoan species in similar environments in Chesapeake Bay. In estuaries and hypersaline lagoons throughout the world the number of species decreases away from the ocean (Emery and Stevenson, 1957; Carriker, 1968; Segerstrale, 1957; Zenkevich, 1957; Khlebovich, 1970; Cuffey, 1970).

Sanders' (1968) concepts of species diversity relating to factors of biological and physical stresses can be applied to the species associations defined here. In areas where physical conditions are relatively constant and uniform for long periods of time, physical stress is not important in controlling success or failure of the species (Sanders, 1968). Through biological interactions, the evolution of biological accommodation occurs. This community is characterized by a large number of stenotopic species. The deep-sea regions, tropical shallow-water marine regions, and to some extent tropical estuaries best represent such conditions (Grassle, 1967; Dobzhansky, 1950).

However, in areas where wide fluctuations in physical conditions are common and the animals are exposed to severe physiological stress, the community is adapted primarily to survive the physical environment (Carriker, 1968). "The physically controlled communities are always eurytopic and are characterized by a small number of species" (Sanders, 1968, p. 252). As the stress gradient increases, the number of species decreases.

In areas of Town and Debidue Creeks where few species occur, the instability of the environment is the controlling factor in limiting the distribution. These areas exhibit the greatest variations in amplitude of environmental factors. Toward the ocean, the environmental stability increases and, therefore, the number of species increases. Because North Inlet is the area of least fluctuation in the physical environment, it contains the largest number of species.

Three distinct associations of stations are apparent from the bryozoan assemblages. Figure 6 shows the areal extent of each of these associations. When the raw data matrix is rearranged by grouping the highly associated stations together (Table 3), the presence and importance of each species can be seen.

If the idea that environmental stress is controlling bryozoan distribution and density is accepted, then the stress tolerance of species can be ranked (Table 3). Each species is categorized by its degree of penetration into the creek systems. Conopeum tenuissimum, found only at the heads of Town and Debidue Creeks (Upper Estuary) is defined here as "true estuarine" (after Carriker, 1968, p. 443). Two species, Membranipora tenuis and Electra monstachys, due to their ubiquitous distributions, are classified as highly tolerant species. Schizoporella errata and Parasmittina nitida do not penetrate as far inland as the two highly tolerant species but do penetrate into the upper extremities of the creeks and are therefore classified as moderately tolerant species. Three species, Cryptosula pallasiana, Microporella ciliata, and Bugula neritina, penetrate only into the area of the Middle Estuary and are therefore defined as low tolerant species. Two species are described as intolerant because of their restriction to the North Inlet waters and the immediate waters of Town Creek (Lower Estuary). These species are Hippoporina verrilli and Membranipora arborescens. The presence and abundance of particular species in a single sample can therefore be used as environmental predictors.

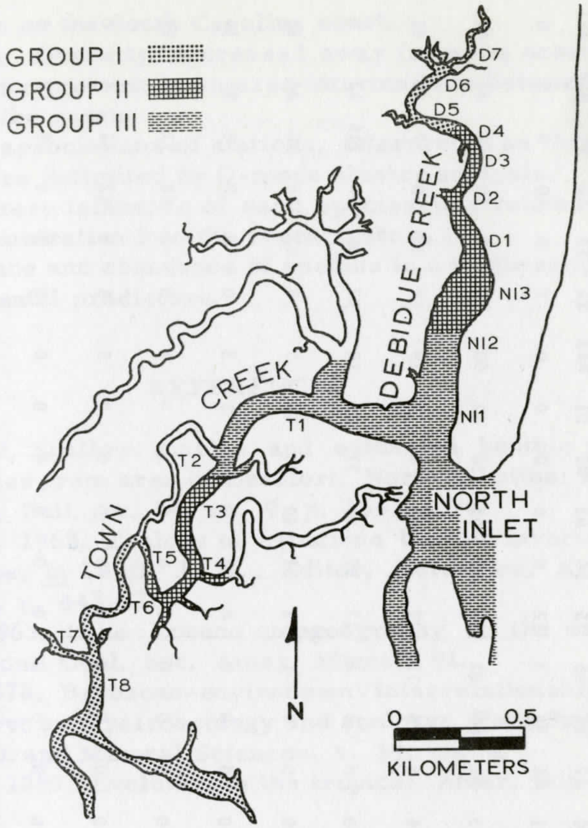

Figure 6. Bryozoan biofacies in North Inlet tidal creek system.

Table 2. Delimitation of Five Significant Categories of Bryozoan Percentage Abundance. Scaled Values are Derived from the Percentages of the Bryozoan Colonies at Each Sample Locality.

Description	Percentage	Scaled Value
Absent	0	1
Scarce	$> 0 \leq 2$	2
Present	$> 2 \leq 10$	3
Abundant	$> 10 \leq 49$	4
Dominant	≥ 50	5

SUMMARY

1. The distribution of Cheilostome Bryozoa was analysed in a

Table 3. Distribution and Abundance of Cheilstome Bryozoa in the Three Biofacies Defined in the North Inlet System. The Environmental Tolerence of each Bryozoa is Indicated.

		[-------- UPPER ESTUARY						--------]	[--------MIDDLE ESTUARY						---------]	[--LOWER ESTUARY--]			
		D7	T8	D6	T7	T6	D5	T5	D4	D3	D2	D1	NI3	T4	T3	T2	T1	NI2	NI1
ESTUARINE	Conopeum tenuissimum	17	10	11	44	38	3	12	0	0	0	0	0	0	0	0	0	0	0
HIGHLY TOLERANT	Membranipora tenuis	0	1	13	61	69	31	40	99	55	20	22	60	10	22	50	61	62	42
	Electra monostachys	0	1	6	6	26	18	12	23	44	8	9	19	15	23	10	7	48	82
MODERATELY TOLERANT	Schizoporella errata	0	0	0	0	3	4	17	97	95	37	25	10	37	30	34	116	12	9
	Parasmittina nitida	0	0	0	0	0	1	2	31	20	20	19	7	6	22	64	78	28	15
LOW TOLERANT	Cryptosula pallasiana	0	0	0	0	0	0	0	5	7	1	5	3	0	0	2	3	26	16
	Microporella ciliata	0	0	0	0	0	0	0	0	0	1	4	1	0	2	28	51	12	11
	Bugula neritina	0	0	0	0	0	0	0	0	0	0	0	5	1	8	12	14	6	0
INTOLERANT	Hippoporina verrilli	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	2	5
	Membranipora arborescens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	8	2
		17	12	30	111	136	57	83	250	221	87	84	105	69	101	201	342	204	182

tidal creek system on the South Carolina coast.

2. Species diversity decreased away from the ocean whereas relative density was greatest in an area intermediate between the heads of the creeks and the ocean.

3. Three associations of stations, interpreted as three distinct environments, were delimited by Q-mode cluster analysis.

4. The stress tolerance of each species was ranked according to its degree of penetration into the creek system.

5. Presence and abundance of species in a single sample can be used as environmental predictors.

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REINTERPRETATION OF AN ARCHAEOCYATHID REEF: SHADY FORMATION, SOUTHWESTERN VIRGINIA

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ABSTRACT

In 1938 C. E. Resser described an archaeocyathid reef from the Lower Cambrian Shady Formation near Austinville, Virginia. Reexamination of this locality reveals that the skeletal structure of Archaeocyatha is not present in what Resser termed an archaeocyathid reef. Resser's archaeocyathids are reinterpreted as thick organically bound burrow walls which, when weathered, appear circular in cross-section and thus superficially resemble archaeocyathids. The burrow complex contains interconnected vertical and horizontal components and is geometrically similar to burrows constructed by the extant ghost shrimp, Callianassa.

INTRODUCTION

In Eastern North America archaeocyathid reefs have been reported from two Lower Cambrian Formations; the Forteau Limestone in Newfoundland and Labrador and the Shady Dolomite in southwestern Virginia. Although several workers have independently confirmed the presence of archaeocyathid reefs in Newfoundland and Labrador (Schuchert and Dunbar, 1934; Kay, 1967; Fong, 1969, Balsam, 1971, 1973) only Resser (1938) and Currier (1935), who used Resser's field data, have published any detailed information concerning the Virginia locality. According to Resser (1938, p. 6) "Archaeocyathid reefs are beautifully preserved in the vicinity of Austinville", Virginia. Those exposures Resser interpreted as an archaeocyathid reef he named the Fossil Point Limestone facies of the Shady Formation and noted that "Since the presence of the reefs has been disclosed, many further discoveries will no doubt be made and from these we may expect details regarding distribution, the extent of the reefs and the contained fauna" (p. 36). To date, no new reefs have been discovered and only a single abstract (Balsam, 1970) has been published on reefs Resser described from the Austinville area. This report deals exclusively with the

Fossil Point Limestone. It concludes that the Fossil Point Limestone cannot be an archaeocyathid reef because it contains no archaeocyathids and proposes a possible origin for the enigmatic structures Resser identified as archaeocyathids.

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AREA OF STUDY

The Fossil Point Limestone is situated on the property of the New Jersey Zinc Co. five-eighths of a mile northeast of the Austinville, Virginia, school (U. S. G. S. 7 1/2 minute quadrangle series; Austinville quadrangle, 36° 51' 04" N. ; 80° 53' 45" W). Figure 1 indicates the location of the Fossil Point facies. Outcroppings assigned to the Fossil Point Limestone occupy an area 500 feet wide, 2500 feet in length, and are exposed in a stream valley where they form small knolls (Resser, 1938, Plate 1) aligned in parallel bands which strike NNE. Where bedding is visible, dip varies from 25° to 35° SSE.

STRATIGRAPHY AND GENERAL GEOLOGY

The Fossil Point Limestone is part of a sequence of fossiliferous limestones and dolomites which are unlike other Cambrian units exposed to the north and west (Palmer, 1971). Currier (1935) and Butts (1940) considered the sequence to be a southeastern facies of the Rome or Elbrook Formations and therefore overlying the Shady Dolomite. However, Stose and Jonas (1938) interpreted this sequence as a southeastern equivalent of the Shady Formation and recognized within it three distinct units (formations). As Palmer (1971, p. 199) noted "final resolution of these conflicting interpretations has not yet been made". Although the exact stratigraphic relationship between the Fossil Point Limestone and the encompassing formations remains uncertain, the presence of fossils indicative of the Early Cambrian establishes its age.

The Fossil Point Limestone is located in a structurally complex area. Even in the small area studied, numerous faults of unknown

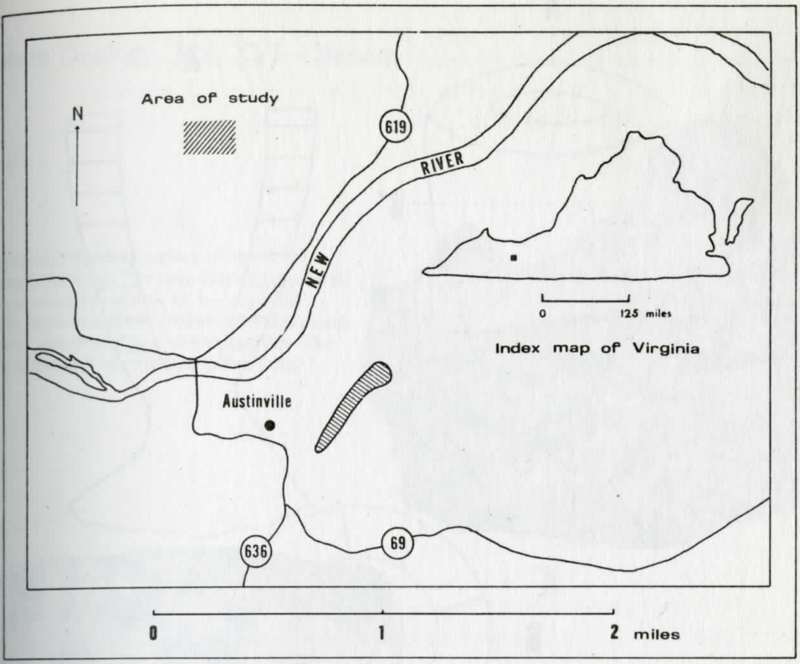

Figure 1. Sketch map showing location of the area studied. Surface exposure of the Fossil Point Limestone is included within this area.

displacement make correlation between outcrops tenuous. Typically, the Fossil Point facies is a dense gray, unbedded, lime mudstone containing frequent masses of sparry calcite. To the northeast and southeast this limestone interfingers with white saccharoidal dolomite while to the southwest it is interbedded with red dolomitic shale that is lithologically similar to the Rome Formation.

LITHOLOGY AND PALEONTOLOGY

Resser's conclusion that the Fossil Point Limestone is an archaeocyathid reef appears to be based solely on interpretation of weathered outcrop surfaces. Because of their vase-like geometry, cross-sections of archaeocyathids are usually circular whereas longitudial sections are U-shaped (Figure 2). Cursory examination of weathered surfaces demonstrates the apparent similarity between undoubted archaeocyathids and what Resser called "Archaeocythinae" (Figure 3). On these surfaces numerous ring-shaped areas that are morphologically similar to archaeocyathid cross-sections were observed. However, U-shaped longitudinal sections were not present on any weathered surface, regardless of its orientation.

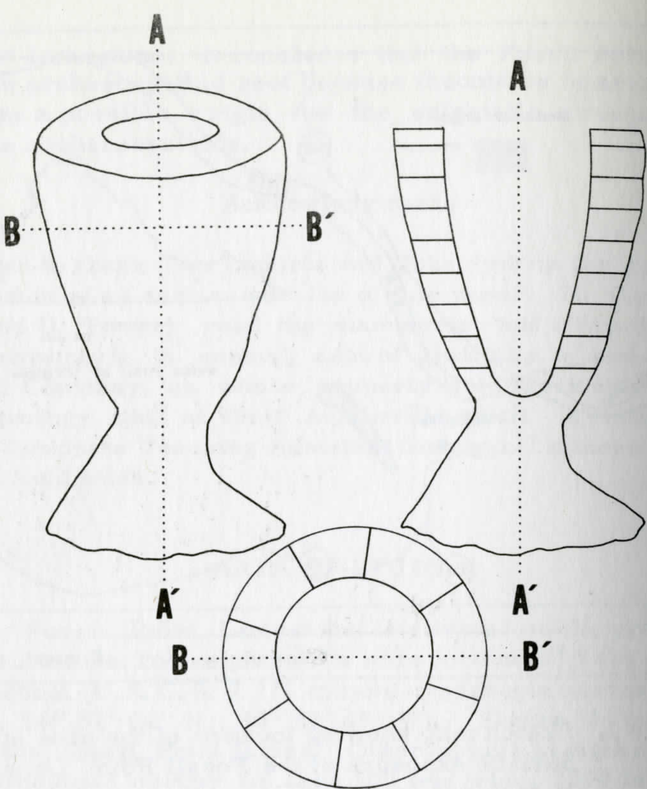

Figure 2. Schematic representation of archaeocyathid skeletal structure illustrating the geometry of a longitudinal section (A-A') and cross section (B-B').

Archaeocyathid skeletal structure was not observed during detailed examination of either polished slabs or thin sections; although skeletal fragments of <u>Obolella</u>, <u>Paterina</u>, <u>Hyolithes</u>, <u>Helcionella</u>, and <u>Olenellus</u> are present. Because of their dense, fine-grained skeleton archaeocyathids should be more resistant to solution than many other invertebrate taxa (Balsam, 1973). Thus, the ring-shaped areas could not result from diagenetic alteration of archaeocyathids. The lack of U-shaped longitudinal sections and the complete absence of internal skeletal structure precludes the possibility that the Fossil Point Limestone contains archaeocyathids, and therefore it cannot be an archaeocyathid reef. Although archaeocyathids are found in the Shady Formation near Austinville, they are few in number.

If then, these structures are not archaeocyathids, what are they? Examination of one hundred polished slabs and thirty-three thin sections reveals that the Fossil Point Limestone contains three distinct lithotypes: 1) dark gray lime mudstone, 2) light gray pelleted mudstone,

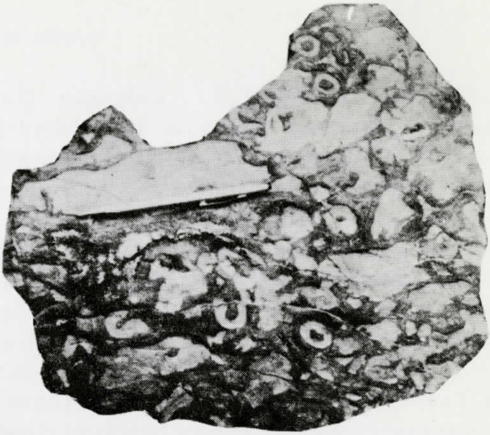

Figure 3. Weathered bedding surface of the Fossil Point Limestone. The ring-shaped structures geometrically resemble archaeocyathid cross-sections and are probably the structures Resser interpreted as archaeocyathids. The pen is five and one-quarter inches long.

Figure 4. Polished slab containing three lithotypes. All polished slab samples illustrated are cut normal to bedding and oriented so that the top of the sample is uppermost on the page. The scale is divided into inch increments.

Figure 5. Polished slab where the dark gray lime mudstone forms irregular horizontal bands. The scale is divided into inch increments.

and 3) calcite spar (Figure 4). The distribution of these three lithologic units is not random; rather they form distinct patterns which are found throughout the Fossil Point facies.

Mudstone

The mudstone appears in all samples, is frequently oriented either parallel or normal to local bedding, and forms vertically connected, irregular horizontal bands (Figure 5). In samples where this lithotype is not oriented it forms ring-shaped and more irregular masses in the pelleted and sparry lithologic components (Figure 6). Circular and ellipsoidal openings filled with spar and/or pelleted mudstone are common in the mudstone; infrequently the mudstone forms tubular structures (Figure 7). Samples cut parallel to local bedding demonstrate that the ring-shaped areas Resser termed archaeocyathids are composed of this dark gray lime mudstone.

Serial sections of the mudstone reveal that it encompasses an interconnected tube system with both vertical and horizontal components. On a single polished surface this tube system may pass in and out of the plane of the cut or it may be by-passed entirely.

Analysis of thin sections shows that this lithotype is predominantly micrite with lesser amounts of pellets (used to designate size with no genetic connotation intended following Folk, 1962), microspar, and skeletal fragments (Table 1). Pellets have diffuse boundaries and are irregular in shape, suggesting that they are agglutinated mud particles rather than of fecal origin (Folk, 1962; 1965).

Pelleted Mudstone

The pelleted mudstone is found in all samples. The percentage of surface area composed of pelleted mudstone varies with the orientation of the mudstone lithotype: Where the mudstone is vertically aligned, the percentage of pelleted mudstone is high (up to 90%); whereas a horizontal alignment of the mudstone results in a lower percentage of pelleted mudstone (as little as 10%). Where the mudstone parallels local bedding, the pelleted lithotype occupies the space directly above it (Figure 5).

Analysis of thin sections (Table 1) shows that this lithotype contains equal quantities of micrite and pellets and a substantial amount of microspar. Skeletal fragments are rare. Pellets in this lithologic component are circular to ellipsoidal in shape, have distinct boundaries, and are well-sorted. This lithotype is composed of alternating layers of pelsparite and microspar which maintain a constant thickness across the length of a thin section (3 inches) and are usually parallel to local bedding. The contact between the mudstone and the pelleted mudstone, although distinct, does not appear to be a solution contact. Skeletal grains which cross this boundary show no evidence of dissolution.

Table 1. Point count data expressed in percent of the total number of points counted. Samples are all two by three inch thin sections; the number of points counted per section averaged 475. Microspar is used to indicate microcrystalline calcite (maximum dimension less than forty microns but greater than four microns) that is found in a finer matrix termed mud. Unknown spar is used to indicate blocky, or elongated pieces of spar that could be of organic origin.

	Pelleted Mudstone					Mudstone				
Sample Number	Skeletal Fragments	Pellets	Micro-spar	Mud	Unknown Spar	Skeletal Fragments	Pellets	Micro-spar	Mud	Unknown Spar
C-4-2	1	36	27	33	3	8	22	29	38	3
C-4-3	2	30	27	39	2	5	24	22	44	5
C-4-1	1	41	30	27	2	2	30	22	46	0
E-2-2	0	26	21	53	0	1	4	9	86	0
B-1-1	0	42	22	34	3	9	3	15	72	1
B-1-2	0	51	32	17	0	16	2	8	74	0
D-2-1	0	49	30	20	0	1	53	8	38	0
Al-2-1	0	36	20	44	0	1	44	12	42	1
C-3	0	37	24	38	0	6	36	17	35	6
X-1	0	40	26	34	0	2	28	9	61	0
Mean	.4	38.8	25.9	33.9	1	5.1	24.6	15.1	53.6	1.6

Figure 6. Polished slab showing the mudstone lithologic component forming ring-shaped and more irregular masses. Note that ring-shaped structures may be infilled either with sparry calcite or pelleted mudstone. The scale is divided into inch increments.

Figure 7. Polished slab illustrating the dark gray lime mudstone forming tubular structures. Note that tubular structures and ring-shaped areas are interconnected. The scale is divided into inch increments.

Table 2. Summary of Lithologic Characteristics.

	Mudstone	Pelleted Limestone	Calcite Spar
Habit	All samples 10-50% of rock volume Volume percent relatively constant	All samples 5-90% of rock volume Volume percent variable Varies inversely with spar	Absent from some samples 0-60% of rock volume. Volume percent highly variable. Varies inversely with pelleted mudstone.
Lithology	Microspar and mudstone	Alternating bands of pelsparite and mudstone	Concentrically banded spar
Skeletal Fragments	5%	1/2%	None
Pellets	25%	39%	None
Shape of Pellets	Irregular with diffuse boundaries	Circular or elliptical with distinct boundaries	None
Microspar	34%	53%	None

Calcite Spar

The calcite spar is white to gray in color, forms coaxial bands, and always has a distinct, often stylolytic, contact with other lithotypes. Spar grain size increases away from the contact with other lithotypes; grains are bladed or elongate in shape with their axes normal to the contact. Bathurst (1958) indicated that the above features are typical of void-filling chemical precipitates. In one sample, a void containing open crystal faces was found in the center of an elongate crystal mosaic. Frequently, the center of elongate mosaics is filled with blocky, more equant calcite crystals. Lithotype characteristics are summarized in Table 2.

INTERPRETATION

Because the dark gray mudstone lithotype exhibits a consistent range of morphologies and therefore appears to control the distribution of other lithologic components, it is probably the key to interpreting the unusual rocks of the Fossil Point Limestone. Circular openings in this mudstone form an interconnected vertical and horizontal tube system with a diameter of about 6 mm. Although tube systems formed by inorganic processes have been reported (for example, sandstone dikes reported by Cloud, 1968) they usually contain only vertical tubes. Furthermore, inorganic processes cannot account for the dense, micritic lithology of the tube walls (mudstone lithotype). Therefore, the tube system is probably of organic origin.

Tube systems, such as found in the Fossil Point Limestone, could be formed only by two types of organic activity: 1) dentritic rooting of plants, or 2) burrowing activity of infaunal animals. If the tube system was formed by plant roots, then the size of the opening should show large variations in its diameter and systematic changes in its dimensions. Such changes were not observed. Furthermore, there is no evidence that rooted plants had evolved by Early Cambrian time. Therefore, burrowing animals probably constructed these tube systems.

In recent sediments, burrow systems with interconnected horizontal levels are constructed by the ghost shrimp, Callianassa (Shinn, 1968). In addition to having a similar geometry, the dimensions of the opening of Callianassa burrows are similar to those of the Fossil Point burrows. These walls of some Callianassa burrows are organically bound (Weimer and Hoyt, 1964). Thus, the dark gray mudstone which forms burrow walls in the Fossil Point Limestone probably were constructed in a similar manner accounting for their darker color and micritic texture. Although these ancient burrows closely resemble modern Callianassa burrows, in view of the long time span involved (about 550 million years), the organisms which constructed them were probably taxonomically distinct.

The pelleted mudstone is interpreted as a biologically reworked sediment (based on the presence of pellets of probable fecal origin) in which larger, organically bound burrows were constructed. The large percentage of skeletal fragments in burrow walls may indicate that biological reworking continued after burrow construction.

Calcite spar is interpreted as filling large voids based on criteria established by Bathurst (1958). The burrow system may have acted as a conduit enhancing fluid movement and dispersion. Furthermore, burrow walls bound by secreted organic material probably resisted solution and may have controlled the pattern of later diagenetic events.

CONCLUSIONS

1) Structures present in the Fossil Point Limestone are not archaeocyathids as reported by C. E. Resser (1938). Scattered archaeocyathids are present in the Shady Formation, but not in what Resser called an archaeocyathid reef.

2) What Resser called archaeocyathids are really cross-sections of organically bound burrow walls. Burrows in the Fossil Point Limestone are similar in size and geometry to burrows constructed by the extant ghost shrimp Callianassa.

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